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by

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ABSTRACT

Water-type solar heating systems have received much attention in the literature and several good computer simulation models are available. Air-type space heating units have advantages which may make them more suited to a particular need than the water-type system.

This computer simulation offers a model of an air-type solar heating system with which one can determine the monthly system output. All significant system parameters are easily varied as is the storage bed size and material. The simulation accepts all air-type collector designs. The residence is simply modeled and estimating its heat load is reduced to calculating the product of floor area times a constant. Insolation data input is based on monthly averaging-techniques.

The quantities varied in the present application of the model were collector size and storage volume.

Thesis Supervisor: James D. Felske
Title: Assistant Professor, Mechanical Engineering

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NOMENCLATURE

Numbers in ( ) refer to the equation(s) in which the symbol appears.

A (12,14,15)	cross-sectional area of pebble bed storage unit m^2
A_c	overall collector area m^2
A_p (13)	total surface area of pebble bed storage unit m^2
A_{xs} (9)	area of collector normal to air flow m^2
b	subscript refering to the storage bed material
c_b (13,15)	specific heat of pebbles in storage bed; assumed constant at 0.837 KJ/Kg - °C
c_f (11-13,15)	specific heat of air; assumed constant at 1.012 KJ/Kg - °C
D (14)	diameter of pebbles, all assumed equal m
D_H (7,9)	characteristic length of collector (hydraulic diameter) for use in determining Reynold's number; equal to twice the spacing between the plates m
d (23)	dust factor
F' (11)	collector efficiency factor [1]
F_R (10,11)	collector heat removal factor [1]
f	subscript refering to the fluid (air)
G (14)	flow rate per unit cross-sectional area of storage bed Kg/s - m^2
G_c (11)	flow rate per unit of collector area Kg/s - m^2
H (16,23)	monthly average daily total radiation on a horizontal surface KJ/m^2 - day

h_1 (7)	convective heat transfer coefficient for collector absorber plate $W/m^2 - °C$
h_2 (7)	convective heat transfer coefficient for collector back plate $W/m^2 - °C$
h_r (6)	radiation heat transfer coefficient between the two air duct surfaces of collector (sides neglected) $W/m^2 - °C$
h_v (12,14,15)	volumetric heat transfer coefficient for storage bed material $W/m^3 - °C$
K_d (16,23)	ratio of the monthly average daily diffuse radiation to the daily extra-terrestrial radiation
K_t (16,23)	ratio of the monthly average daily total radiation to the daily extraterrestrial radiation
k_{air} (7)	thermal conductivity of air, taken to be constant at 0.029 W/m - °C
k_{ins} (5)	thermal conductivity of insolation used under collector, taken to be constant at 0.043 W/m - °C
L (12,15)	length of storage bed m
m (12,13)	subscript referring to the mth segment of the storage bed
m (9,12,13,15)	mass flow rate of air Kg/s
N (1,25):(20)	number of glass covers: day of year measured from January 1
Nu (7,8)	Nusselt Number
n (12,13,15)	number of segments into which the storage bed is considered to be divided for application of numerical technique
n_g (27)	refractive index of glass

Q_u (10)	hourly rate of useful thermal energy collection per unit area of collector surface W/m^2
R_b (16,17,23)	ratio of radiation on a tilted surface to that on a horizontal surface
$R_{e_{D,H}}$ (8,9)	Reynold's Number for collector air flow based on hydraulic diameter
r_d (16,21,23)	ratio of hourly to daily diffuse radiation
r_t	ratio of hourly to daily total radiation
S (19,23)	hourly flux of solar radiation absorbed by collection surface W/m^2
SI (16)	hourly flux of solar radiation striking a tilted surface W/m^2
S (23)	shading factor
T_{amb} (1,10)	ambient temperance °C
$T_{c,i}$ (10)	inlet air temperature to the collector °C
T_{b_m} (12,13)	temperature of pebbles contained in storage segment m
T_{f_m} (12,13)	temperature of air entering storage segment m °C
$T_{f_{m+11}}$ (12,13)	temperature of air leaving storage segment m+1 °C
$T_{f,m}$	mean fluid temperature in collector
T_p (1)	mean absorber plate temperature during operation of collector °K
T_s (13)	temperature of the surroundings containing the storage bed °C
$\overline{T}$ (6)	mean temperature for radiation between the absorber plate and back plate of collector, assumed constant at 340°K

T_1 (6)	mean temperature of absorber plate °K
T_2 (6)	mean temperature of back plate °K
t_{ins} (5)	thickness of insulation behind back plate m
U_b (5)	overall collector back loss coefficient W/m^2 - °C
U_L (10,11)	overall collector loss coefficient W/m^2 - °C
U_{Ls} (13)	overall storage loss coefficient W/m^2 - °C
$U_t(45°)$ (1,4)	overall collector top loss coefficient for a unit tilted 45 from the horizontal W/m^2 - °C
$U_t(\beta)$ (4)	overall collector top loss coefficient for a unit tilted degrees from the horizontal W/m^2 - °C
V (3)	wind velocity, assumed constant at 5 m/s
α	solar altitude
$\alpha(\theta_t)$ (24,28)	directional absorptivity of collector plate
β (4,16,23)	collector tilt from horizontal
γ (18)	surface azimuthal angle (due soth being zero and east positive)
δ (18-20,22)	declination
ε (13,15)	void ratio of storage bed
ε_g (1)	emissivity of glass cover plates
ε_p (1)	emissivity of absorber plate
ε_1 (6)	emissivity of absorber plate
ε_2 (6)	emissivity of back plate
θ_t (17,18,24-27)	angle of incidence of direct radiation measured from the normal to the collector

θ_2 (26,27)	angle of refraction	
μ (9)	absolute viscosity	Kg/m-s
ρ (13,15)	density of pebble bed material	Kg/m^3
ρ_{gr} (16,23)	diffuse ground reflectivity	
$\rho(\theta_t)$ (25,26)	reflectivity of a single air-glass interface for direct radiation as a function of ϕ_t	
$\rho(60\ )$ (24)	reflectivity of a single air-glass interface for diffuse radiation	
τ (12,13,15)	time	s
$\left.\begin{matrix}(\tau\alpha)_{eff,b}\\(\tau\alpha)_{eff,d}\end{matrix}\right\}$ (23)	effective transmittance - absorptivity product for direct (beam) radiation and diffuse radiation, respectively	
$\tau(\theta_t)$ (24)	directional transmittance of glass as a function of θ_t	
ϕ (18,19,22)	latitude (north positive)	
ω (18,19,21)	hour angle (solar noon zero and morning positive)	
ω_s (21,22)	hour angle corresponding to sunrise (and sunset since the day is assumed symmetric about solar noon)	

$$\sigma = 5.6693(10)^{-8}\ W/m^2 - {}^\circ K^4$$

I. INTRODUCTION

This study was undertaken for the purpose of developing a computer simulation of an air-type residential solar space-heating model from which to determine the optimum collector and storage size for a given heat load. Furthermore, the need for comparison between this and liquid-type systems dictated that the model developed be adaptable to changes in various significant parameters and components.

To date the majority of published computer simulation models, as well as actual installations, has been of the "liquid-type", that is, a solar heating system wherein water or a water-antifreeze solution is the working fluid [7]. The most noteable exception to this trend has been the simulations and installations of Dr. G. Löf.

Liquid-type systems are favored [7] for commercial installations where a large amount of energy must be distributed. In such a case the storage tank, piping and insulation required occupies far less valuable space than would the storage and ductwork necessary to transport the same amount of heat using air at reasonable rates of flow. Also, the basic components (heat exchangers, pumps and controls) associated with the liquid-type system become proportionally less expensive as the size of the system they serve grows.

On the scale of a single-family dwelling however, it appears a trade-off becomes practicable between liquid and air systems depending upon the geographic location, nature of an existing conventional system (for retrofit solar installations) and extent of solar energy utilization desired, among other considerations. Some salient trade-off considerations of the two types of systems currently most widely employed are summarized in Table 1. Though not exhaustive, this indicates generally some of the more significant differences between the systems.

These points serve only as a first-cut at making an overall system evaluation because various design strategies may be employed to lessen the disadvantages of the liquid system or extend the utilization of the air system.

For example, if in a water-type system the space heat is supplied by blowing air over a heat exchanger directly into the room, instead of relying on natural convection from baseboards or radiators, lower water temperatures may be acceptable. Solar system efficiency increases significantly when the thermal energy is absorbed at the lowest useful temperature. This heat transfer can be accomplished at the storage container (e.g., in a rock bed or finned annulus surrounding the tank) with standard ducting distributing the heated air throughout the

TABLE 1: Comparison of relative merits of liquid and air-type solar heating systems. "Liquid" refers water or water-antifreeze solution as the thermal energy transport medium coupled to a water storage tank. "Air" refers to air as the transport medium with a rock bed for storage.

The base for comparison is space heating with additional abilities treated as advantages over this.

LIQUID

ADVANTAGES

1. smaller storage volume per unit of heat stored
2. transport network occupies smaller space
3. directly adaptable for use with absorption A/C equipment
4. directly adaptable to domestic hot water supply
5. adaptable to either forced-hot-water <u>or</u> forced-hot-air
6. if chilled-water air-conditioning is supplied, one distribution system serves for both heating and cooling

DISADVANTAGES

1. more complex controls, heat exchangers required in most applications, maintainance more costly
2. Less efficient energy collection at temperatures required for forced-hot-water baseboard heating (140-190°F)
3. may require some treatment of transport liquid, such as: antifreeze, antiscale, anticorrosive or biocide
4. possibility of expensive damage in dwelling due to collector leakage, or to collector due to freeze-up
5. water may be scarce commodity; antifreeze (oil by-product) has uncertain future cost and availability
6. where central air conditioning is supplied, forced-hot-water heat requires parallel distribution system (pipes) for space heating

AIR

ADVANTAGES

1. simple operation, longer lifetime, less maintainance, less capital and installation cost
2. since the transport fluid is identical to the ultimate delivery medium, no heat exchanger, per se, is necessary
3. system can be adapted, though not readily, to cooling of dwelling*
4. where central air conditioning is supplied, one distribution system serves for both heating and cooling (ductwork sized for the mass flow rates associated with A/C lends itself to collection of heat at the lowest temperature)
5. air is free, rocks are plentiful and leaks are neither dangerous nor damaging

DISADVANTAGES

1. not readily adaptable (possibly not feasible) to providing source of heat for conventional air conditioning equipment
2. where (finned tube) heat exchangers are used, they must be larger than that required in a liquid-system to transfer the same quantity of energy
3. ducting and storage require more space for the same energy transport or storage, respectively

*e.g., cool storage at night for use during the day.

dwelling. Alternatively the heated water can be piped to those locations where space heat is required and air blown over a coil-type heat exchanger into the space. The latter scheme might be advantageous where space is at a premium or where the distribution network is extensive.

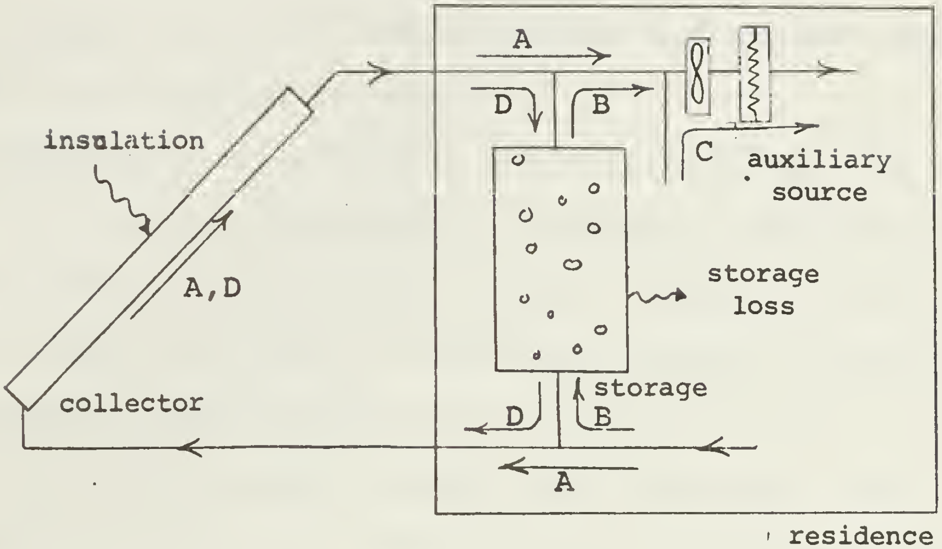
On the other hand, by placing a water coil within the rock bed of the air-type system or girdling the bed with such a coil, preheated or fully heated domestic hot water can be provided. Alternatively, by cooling the rock bed by night with ambient air, the dwelling can be cooled during the day using the storage as a heat sink. The materials of the rock bed being rather low in cost, it might be worthwhile to provide a <u>separate</u>, uninsulated storage bed a meter or so underground to be cooled at night in the above manner while also losing heat to the ground; this unit would be exclusively for summer air conditioning and sized accordingly. The main storage unit, well insulated and connected to the collector, would be used to heat domestic hot water (as described above) and would be available, as well, to provide space heating as needed on cool summer nights or days. This latter bed would be sized for winter space heating.

As can be seen, hybridization and innovation can be used to great advantage, especially in adapting to an

already existing conventional system, but makes a clear-cut determination of the "best" system for a given situation very difficult. Regional weather characteristics and labor rates, the cost in dollars of one system versus another (including various levels of component refinement in each case) and the availability of materials (e.g. a reliable source of water or antifreeze) only complicate further a fundamentally complicated problem in thermodynamics. To this end, "canned" computer simulations appear to offer the most direct and cost-effective manner of gleaning from the myriad of interrelationships the optimum design for a given dwelling and location.

II. DESCRIPTION OF THE SOLAR HEATING SYSTEM SIMULATED

A schematic diagram of the solar space heating system employed in this study appears in Figure 1. The residence is heated by forced-hot-air. The flat plate collector transforms the absorbed portion of the incident solar radiation into thermal energy which is then extracted by the working fluid passing over the heated absorbing plate (see Figure 2). This heat transfer is accomplished with air, the ultimate delivery medium. When satisfying immediate heating requirements of the dwelling, air circulates directly between the collector and dwelling - cycle A - if useful heat is available. When no solar energy is directly available, the room air is circulated through the storage medium - cycle B - if useful heat is available there. Should there be a requirement for space heating beyond the capacity of both these processes, auxiliary heat - cycle C - is provided to make up the deficit. Finally, when solar energy is available for which there is no immediate need, the working fluid is circulated through the storage medium transferring thermal energy thereto. As structured, the absence of independent heat exchangers (the pebble bed is at once the storage medium and a single heat exchanger)



CYCLE

A heating dwelling with collector

B heating dwelling with storage (no useful heat available from collector directly)

C heating dwelling with auxiliary source (not enough useful heat available from collector or storage)

D Heating storage with the collector (dwelling requires no heat)

FIGURE 1: Schematic diagram of the solar space heating system used in this study. Operational modes are listed in order of precedence.

disallows the ability to charge and discharge storage simultaneously as is possible in liquid-type systems. Since the transport fluid can also be used as the delivery medium, however, no advantage is lost.

Auxiliary heat, necessary for those periods when no direct or stored solar energy is available from the system, is provided by a conventional heater. Mounted in the outlet duct as shown in Figure 1, this heat exchanger (electrical resistance or gas/oil fired) has an auxiliary inlet in order that circulation through storage does not occur. An exception to this logic could be the case where off-peak electrical rates make charging storage with auxiliary, off-peak energy economical thus supplementing storage input from the collector.

The storage bed is considered to be located within the heated space, therefore convective heat losses from the unit are regarded as an uncontrolled gain to the room.

As shown, the location of the circulation fan would cause a reduced-pressure in the collector. Collectors for such systems are difficult to seal and this configuration would allow infiltration of cold air. However, this has the effect of lowering the overall collector temperature resulting in more efficient operation at the expense of lowering the collector outlet temperature. If one intends

to collect the thermal energy at the lowest useful temperature anyway, this method would appear to offer an advantage. This simulation does not involve such considerations, nor does it account for pressure-drops through storage or elsewhere. In this regard, it is assumed peripheral calculations have addressed compatability between mass flow rates used and various flow areas in the system (collector and ducting cross-sections, pebble-bed effective flow cross-section, etc.).

III. SIMULATION OF THE SYSTEM COMPONENTS

A. Collector

Several flat-plate collectors are available for air-type solar heating systems. This simulation is written to accept such units when the collector characteristics have been reduced to expressions for U_L and F'. The derivation of these terms and other factors for a given collector geometry is given in [1]. The particular collector geometry chosen for this simulation is shown schematically in Figure 2.

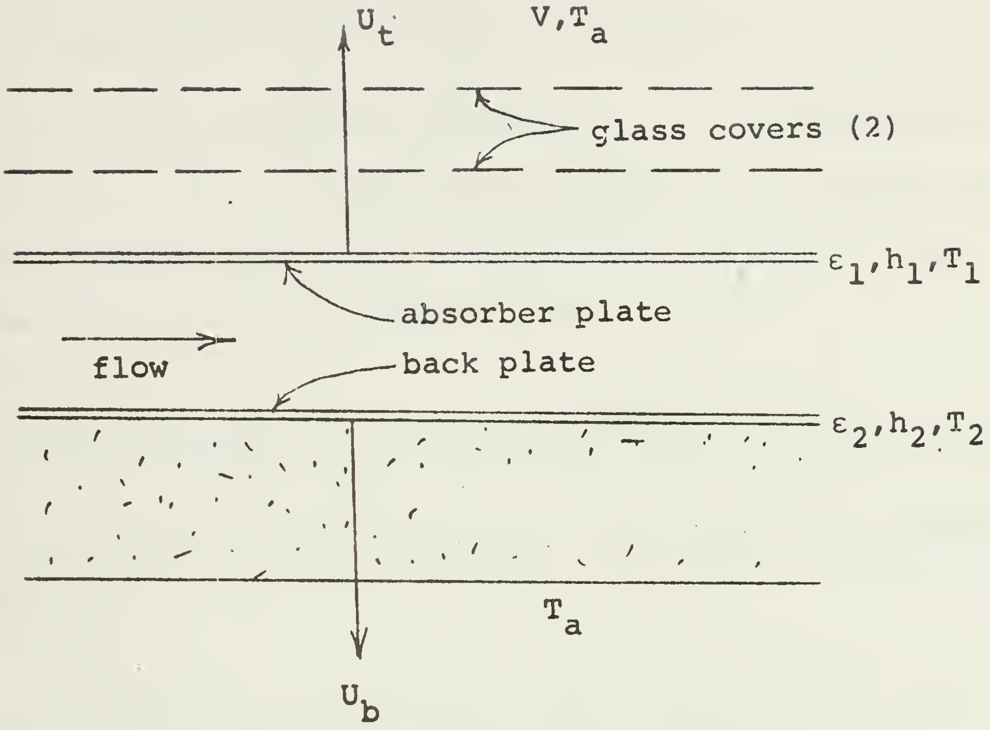
To reduce computing costs, the empirical relationship developed by Klein for the top loss coefficient, U_t (45°) was used:

$$U_t\ (45°) = \left(\frac{N}{(344/T_p)\left[(T_p - T_{amb})/(N+f)\right]^{0.31}} + \frac{1}{h_w}\right)^{-1}$$

$$+ \frac{\sigma(T_p + T_{amb})(T_p{}^2 + T_{amb}{}^2)}{[\varepsilon_p + 0.0425N(1-\varepsilon_p)]^{-1} + [(2N+f-1)/\varepsilon_g] - N} \qquad (1)$$

where

$$f = (1.0 - 0.04\ h_w + 5.0(10)^{-4}\ h_w{}^2)(1 + 0.058\ N) \qquad (2)$$



$$U_L = U_t + U_b$$

$$F' = \frac{1}{1 + \dfrac{U_L}{h_1 + \dfrac{1}{1/h_2 + 1/h_r}}}$$

FIGURE 2: Schematic of Collector Used in This Simulation (Elevation)

and

$$h_w = 5.7 + 3.8\ V \qquad (3)$$

(See NOMENCLATURE section for definitions)

As this expression corresponds to a collector tilt angle, β, of 45°, an additional equation to interpolate for any tilt angle (and, incidentally, for plate emissivities other than 0.95) was employed [1]:

$$U_t(\beta) = U_t(45°)\,[1 - (\beta-45)(0.00259 - 0.00144)\ \varepsilon_p)] \qquad (4)$$

where f is dimensionless, V is in m/s, all temperatures are in °K and h_w, U_t (45°) and U_t (β) are in units of W/m²-°C.

In equation (1) the mean plate temperature, T_p, is not known. As a result, an iterative solution is used in the determination of U_t (45°), (see Appendix). Wind velocity, V, is taken as a constant year round but is easily varied if desired. The expression used for the back loss coefficient is:

$$U_b = k_{ins}/t_{ins} \qquad (5)$$

Thus the overall collector loss coefficient, U_L, is determined to be:

$$U_L = U_t + U_b \qquad (6)$$

The term h_r, representing the radiative heat transfer coefficient between the back and absorbing plates (the sides of the duct being neglected in the heat transfer), is determined from the righthand-most expression below:

$$h_r = \frac{\sigma(T_1+T_2)(T_1^2+T_2^2)}{1/\varepsilon_1+1/\varepsilon_2-1} \approx \frac{4\sigma\bar{T}^3}{1/\varepsilon_1+1/\varepsilon_2-1} \qquad (7)$$

where $\bar{T}$, the mean temperature for radiative heat transfer, is taken as 340°K. This assumption is not critical for the varying conditions encountered in normal operation [1].

The convective heat transfer terms - h_1 and h_2 -, taken to be equal, are based on a fully developed forced turbulent air flow between the parallel, flat plates. For the mass flow rate and all the collector sizes used in this simulation, the Reynold's Number (based on the hydraulic diameter) was greater than 2100 and the length-to-diameter ratio is larger than 10, thereby justifying the assumption. If this is not the case, one must consider the effect of the developing boundary layer (see Section 4.13 of [1]). The resultant expression is:

$$h_1 = h_2 = Nu\ (k_{air}/D_H)\ , \quad W/m^2\text{-}°C \qquad (8)$$

where

$$N_u = 0.0158 \left(\frac{m\ D_H}{A_{xs}\ \mu} \right)^{0.8} \tag{9}$$

With these relations and that for U_L, F' is determined:

$$F' = \cfrac{1}{1 + \cfrac{U_L}{h_1 + \cfrac{1}{1/h_2 + 1/h_r}}} \tag{10}$$

Depending upon the current temperature of the room or storage "cool side" (either of which might be the collector inlet temperature depending on the operating mode in effect) the energy absorbed by the collector may or may not be available at a useful temperature. The expression for useful energy gain from the collector per unit area in either case is [1]:

$$Q_u = F_R\ [S - U_L(T_{c,i} - T_{amb})] \tag{11}$$

where F_R is the collector heat removal factor equal to [1]:

$$F_R = \frac{G\ C_p}{U_L}\ [1 - \exp(-\ U_L F'/G\ C_p)] \tag{12}$$

In the simulation, if the derived quantity Q_u is negative or zero, the collector is not operated. Assuming S, the absorbed solar energy (see equ. (24)) is positive the interpretation of a negative value of Q_u is that if run, the collector

would be operating at an average temperature too high relative to the energy being absorbed to result in an increase in fluid temperature. Expressed differently, more thermal energy would be lost to the surroundings than is being absorbed by the collector.

Due to the long-term nature of the energy balance simulated, the thermal capacitance of the collector was neglected. This is justified because the thermal energy "lost" in bringing the collector to operating temperature in the morning, is subsequently returned to the system at the end of the solar collection period. If the time response of the system were of interest, for control purposes for example, this simplification would not be valid.

Neglected also was a consideration of the trade-off involved between collecting marginal amounts of useful energy and the electrical energy expended by the circulation fan to do so.

Collector tilt was taken to be about 20° greater than the latitude which emphasizes that this simulation intends to size the collector for midwinter heating. Between the practical range of tilt angles (latitude $\pm$ 23.45°), particular angles favor particular collection schemes. For example, β = (latitude + 23.45°) results in the largest

ratio of absorbed-to-incident solar energy occuring on December 21 - this favors space heating. If β = (latitude - 23.45°), the largest ratio occurs on June 21 and favors energy collection on that day.

This simulation assumes an absorber plate emissivity for long wave radiation of 0.95. With selective surfaces available at higher cost, this value can be depressed while maintaining reasonable solar absorptance values. When mass-production techniques are employed to reduce the cost, the significant increase in absorbed energy should justify the additional expense.

The effect of dust on the coverplates is accounted for as is shading due to the collector frame work. The number of covers is taken to be two. Ground reflectance [1] is taken as 0.2 year-round which is conservative because a value of 0.7 is suggested when there is snow cover.

See Section III.E. for the equations used to determine S, the absorbed portion of the radiant energy SI incident upon the outermost coverplate of the titled collector.

B. Storage

The pebble bed storage model is taken from Mumma and Marvin [2]. Two difference equations comprise the mathematical model with one derived from an air-side energy balance and the other from the pebble-side. The equations used are [2]:

$$T_{f_{m+1}} = (T_{f_m} - T_{b_m})\exp[-(h_v\ AL)/\dot{m}\ C_f\ n)] + T_{b_m} \tag{13}$$

and

$$T_{b_m}(\tau+\Delta\tau) = \frac{[\dot{m}\ C_f(T_{f_m}(\tau) - T_{f_{m+1}}(\tau)) - U_{Ls}A_p(T_{b_m}(\tau) - T_s)]}{(\rho AL/n)(1-\varepsilon)C_b} + T_{b_m}(\tau) \tag{14}$$

where subscript f refers to the air, subscript b refers to bed material (rock), τ is time and subscript m refers to one of the n segments into which the storage bed is divided for using the model. Other terms are defined in NOMENCLATURE.

The term h_v is the volumetric heat transfer coefficient defined by [1]:

$$h_v = 650 \left[\frac{G/A}{D}\right]^{0.7} \frac{W}{m^3\text{-}°C} \tag{15}$$

The procedure to use these equations is [2]:

(a) Assume an initial bed temperature distribution at time equal zero.

(b) For a specified bed inlet fluid temperature, evaluate the fluid temperature entering and leaving all n sections of the bed using equation (13).

(c) Evaluate the new bed temperatures at each section after a time increment $\Delta\tau$ using equation (14).

(d) Step forward in time by $\Delta\tau$.

(e) Return to step (b) and repeat.

The "specified bed inlet fluid temperature" is either the room temperature or collector outlet temperature depending upon the operating mode. The time step, $\Delta\tau$ in seconds, can be any value between 0 and 3600 in this simulation, corresponding to the various operational profiles which are possible. In order to insure that the solution be stable, the time step in use must satisfy the following, [2]:

$$\Delta\tau \leq \frac{(\rho AL/n)(1-\varepsilon)c_b}{\dot{m}\, c_f[1-\exp(-h_v AL/\dot{m}\, c_f\, n)]} \tag{16}$$

The computer simulation used automatically determines the largest number of storage sections, n, which will insure a stable solution for the largest possible time step which may occur - 3600 sec.

In a well-designed storage bed the pebble size is small enough that the temperature gradient in the individual pebbles is insignificant [1]. Physically this means the only significant resistance to heat transfer to or from the storage medium is that due to the convective heat transfer phenomenon occuring at the surface of the pebbles.

The convective heat transfer coefficient associated with the surface of the pebbles represents a thermal resistance over which we have little control. On the other hand, we can manipulate to some extent the thermal response of the interior of the pebbles by advantageously choosing the size and shape of the pebble in relation to its material composition. It is generally accepted [3] that if the Biot number (representing the ratio of internal resistance to external heat transfer resistance) is less than 0.10, then computational error resulting from assuming a uniform temperature within the pebble will be less than 5%. This assumption has been made here in order to represent the

volumetric heat transfer coefficient, h_v, by equation (15). If the pebble size is to be varied to examine the effect, this should be taken into account.

The void ratio, ε, is chosen to be 0.3. This corresponds to a body-centered-cubic packing arrangement of exactly similar spheres. Practically, this is the smallest ratio which might occur.

Early trial simulations included unsteady conduction in order to destratify the temperatures in the storage segments while storage was idle. The standard explicit numerical technique used [3] introduced unacceptable errors due to the relatively large longitudinal dimension of the storage segments. This length is dictated by other stability requirements. An implicit method may have improved the results but, no such capability is presently included in this simulation. Though less elegant, it is believed no misrepresentation of the storage response occurs due to neglecting this effect.

During the heating season, taken here to be September through May inclusive, the storage bed is assumed to be located within the residence such that convective losses from storage are not "lost" at all but contribute to the thermal energy requirements of the dwelling.

For the months of June, July and August it is assumed these losses take place to the ambient temperature. In actual practice the storage bed would probably be located in the basement of the dwelling where some of the convective loss would be recovered but a significant portion would be lost to the ground. In order to avoid unnecessary complication, the rather artificial device of locating the storage bed based on the season was used in order not to unreasonably misrepresent one operating mode more than the other.

All the fluid and storage material (rock) properties were considered constant at mean system operating temperature values (see Table 2).

C. Residence

The residence is modeled as a degree-day heat sink. It was chosen to correspond in that characteristic, and size, to that used by Butz [4] in his water-type system (17,000 Btu/°F-day = 374 w-hr/°C-hr). Assumed to be a box-like structure, it has dimensions of 45' x 40' x 8' with standard construction materials, 3 inches of insulation, 2 x 4's on 16-inch centers and 15% fenestration. The effects of heat loss through the floor, infiltration of outside air, solar radiation through unshaded windows and internal heat generation from occupants and electrical appliances were considered by Butz. Considering only the walls, roof and windows as media through which conductive and convective heat transfer may take place, one arrives at a figure of 18,200.0 Btu/°F-day; a 7% error which overpredicts the energy need. It appears a much less strenuous calculation may be adequate to characterize a residence.

The model produces data based on the following assumptions regarding a desirable home heating scenario:

(i) During the heating season the comfort range is between 67.0-70.0°F (19.4 - 21.1 °C) between the hours of 0630 and 2230 and 62.0 - 65.0°F (16.7 - 18.3 °C) for

the remainder of the 24 hour period. For the purpose of determining storage loss to the surroundings or collector inlet temperature during direct residence heating from the collector, the mean of the desired temperature range in effect is used. It is tacitly assumed that the residence is within the desired temperature range at all times by some combination of direct, stored or auxiliary energy.

(ii) During June, July and August the desired room temperature is between 70.0 - 73.0°F (21.1 - 22.8 °C) between hours of 0630 and 2230 and 65.0 - 73.0°F (18.3 - 22.8°C) for the remainder of the 24 hour period. Although during these months storage temperatures are allowed to be 180°F (a temperature too high to be acceptable for space heating), space heating would in fact be possible with a simple mixing damper in the ductwork. The effect would be to divert only part of the fixed air flow through storage. The present model does not account for this possibility and simply provides auxiliary heat when necessary during these summer months.

(iii) If the ambient temperature is greater than the desired room temperature but less than the maximum acceptable room temperature (73.0°F) no input of any kind is provided.

D. Auxiliary Heat

Auxiliary heat is supplied in the amount necessary to make up the deficit between that which the solar heating system is able to provide (including uncontrolled storage losses to the room) and that required by the residence.

E. Insolation and Weather

The method of Liu and Jordan [5] was used in this simulation to provide insolation input. The development and application of this method follows directly that of Felske [6]. In this approach, actual hourly values of insolation for an entire year are unnecessary. Instead, this method requires only that the monthly average values of H; K_T and K_d be determined for a given location. These terms are defined in NOMENCLATURE and [5] explains how they are derived. The location used in this study was arbitrarily chosen to be New York City (40.77°N).

With the above parameters determined for each month, one is able to calculate for an average day of that month, the hourly flux of solar radiation incident upon the collector from the equation [6]:

$$SI = \underbrace{r_d H\{[R_b(1-K_d/K_t)]}_{\text{beam}} + \underbrace{[1/2\ (1+\cos\beta)K_d/K_t]}_{\text{diffuse sky}}$$

$$+ \underbrace{[1/2\ (1-\cos\beta)\rho_{gr}]\}}_{\text{diffuse ground reflection}} \qquad (17)$$

where it is assumed that $r_t = r_d$ and:

$$R_b = \frac{\cos\,\theta_t}{\sin\,\alpha} \tag{18}$$

$$\cos\theta_t = \cos\delta\,\cos\omega\,(\cos\gamma\,\sin\phi\,\sin\beta + \cos\phi\,\cos\beta)$$
$$+ \sin\gamma\,\sin\beta\,\cos\delta\,\sin\omega$$
$$+ \sin\delta(\sin\phi\,\cos\beta - \cos\gamma\,\cos\phi\,\sin\beta) \tag{19}$$

$$\sin\alpha = \sin\delta\,\sin\phi + \cos\delta\,\cos\phi\,\cos\omega \tag{20}$$

$$\delta = 23.45\,\sin\,[360\,(284 + N)/365] \tag{21}$$

$$r_d = \frac{\pi}{24}\,\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s\cos\omega_s} \tag{22}$$

$$\cos\omega_s = -\,\tan\phi\,\tan\delta \tag{23}$$

where N is here the number of consecutive days to mid-month, measured from January 1. When the quantity SI is negative or zero the collector was not operated.

Of course the insolation striking the tilted, outermost surface of the collector is not the energy which ultimately reaches the absorbing plate. The hourly rate of radiation

striking and being absorbed by the collector plate (accounting for dust, shading, reflections and absorption) was computed from the relation [6]:

$$S = (\tau\alpha)_{eff,b}\, r_d H [R_b\ (1-K_d/K_t)] + (\tau\alpha)_{eff,d} \frac{r_d H}{2} [(1+\cos\beta)K_d/K_t + (1-\cos\beta)\rho_{gr}](1-s)(1-d) \tag{24}$$

where from [6]:

$$(\tau\alpha)_{eff} = \frac{\tau(\theta_t)\ \alpha(\theta_t)}{1-[1-\alpha(\theta_t)]\rho(60°)} \tag{25}$$

and

$$\tau(\theta_t) = \frac{1-\rho(\theta_t)}{1+(2N-1)\rho(\theta_t)} \tag{26}$$

$$\rho(\theta_t) = \frac{1}{2}\left[\frac{\sin^2(\theta_2-\theta_t)}{\sin^2(\theta_2+\theta_t)} + \frac{\tan^2(\theta_2-\theta_t)}{\tan^2(\theta_2+\theta_t)}\right] \tag{27}$$

$$\theta_2 = \sin^{-1}\left[\frac{\sin\theta_t}{N_g}\right] \tag{28}$$

in which N equals the number of glass cover plates and other terms are defined in NOMENCLATURE.

Reference [6] indicates that the directional absorptivity of the collector surface, $\alpha(\theta_t)$, can be represented by a curve for a typical surface. The equation provided by Felske to represent this typical curve is:

$$\alpha(\theta_t) = 1.0 - \frac{20.03}{(100.03 - \theta_t)^{1.3}} \qquad (29)$$

where θ_t assumes its actual hourly value for beam radiation but is assigned the value of 60° when used to represent the diffuse radiation component [6].

The hourly ambient temperature distribution is more random than insolation and it can probably be argued that one reasonable distribution of the average daily temperature is about as good as another. In this simulation, the scheme illustrated in Figure 3 was used. The average daytime temperature and nighttime temperature were cast on a sine wave peaking at 1300 hours (Note: throughout this simulation, hourly values are referenced to solar time).

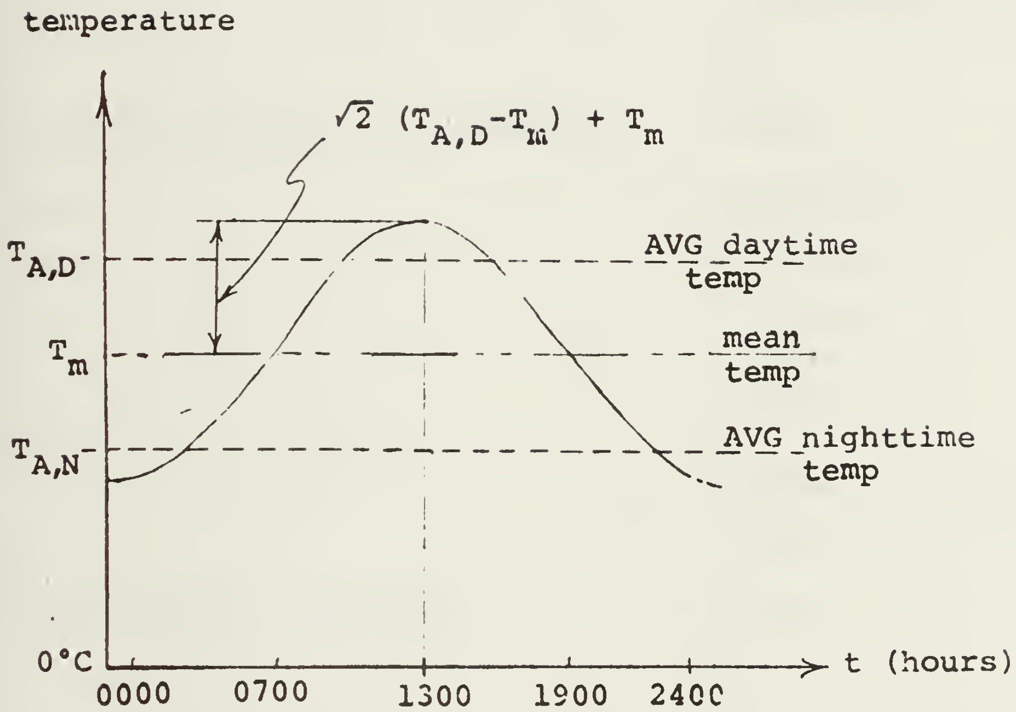


FIGURE 3: Distribution of Ambient Temperature Through the Day

TABLE 2

Simulation Design Parameters

c_b	0.837 KJ/Kg-°C
c_f	1.012 KJ/Kg-°C
d	0.02
Insulation thickness, collector	0.076m
k_{air}	0.029 W/m-°C
k_{ins}	0.043 W/m-°C
$\dot{m}$	1.2 Kg/s
D	0.0508m
N	2 (number of covers)
n_g	1.526
Plate spacing, collector	0.01m
s	0.03
V	5.0 m/s
$\alpha(60°)$	0.8346
β	60°
ε	0.3
ε_g	0.88
ε_1	0.95
γ	0.0

μ (absolute viscosity)	$1.912(10)^{-5}$ Kg-m/s
ϕ	40.77° N
ρ	2400 Kg/m^3
ρ_{gr}	0.2

TABLE 3

Approximate Time Constants for Major System Components

Values for collector and storage are based on the basic component parameters, assumed constant at approximately the mean operating temperature associated with each component.

The value for the residence is calculated based on the time to change the interior temperature of the author's home a given number of degrees over a period of time with constant ambient temperature and no heat input.

Collector:	1/4 hour
Storage Bed:	1 hour
Residence:	10 hours

IV. OPERATIONAL LOGIC AND STRATEGY

The flow chart of Figure 4 represents the operation of the solar system. A breakdown of the computer logic used to implement this basic logic appears in the Appendix.

This simulation operates by accounting for the following heat transfers from and into the residence unit:

a. The heat loss from dwelling driven by the difference between the desired room temperature and ambient temperature.

b. Heat supplied directly to the dwelling from the collector on an as-needed basis when available.

c. Heat supplied to the dwelling from the storage bed in the form of either uncontrolled convective losses or forced-hot-air plus the uncontrolled losses.

d. Heat supplied from the collector to the storage bed.

e. Auxiliary heat as necessary to meet what remains of the heat load should sources (b) and (c) prove insufficient to meet the entire demand.

NOTE: Energy cannot be supplied to room by both collector and storage during the same hour.

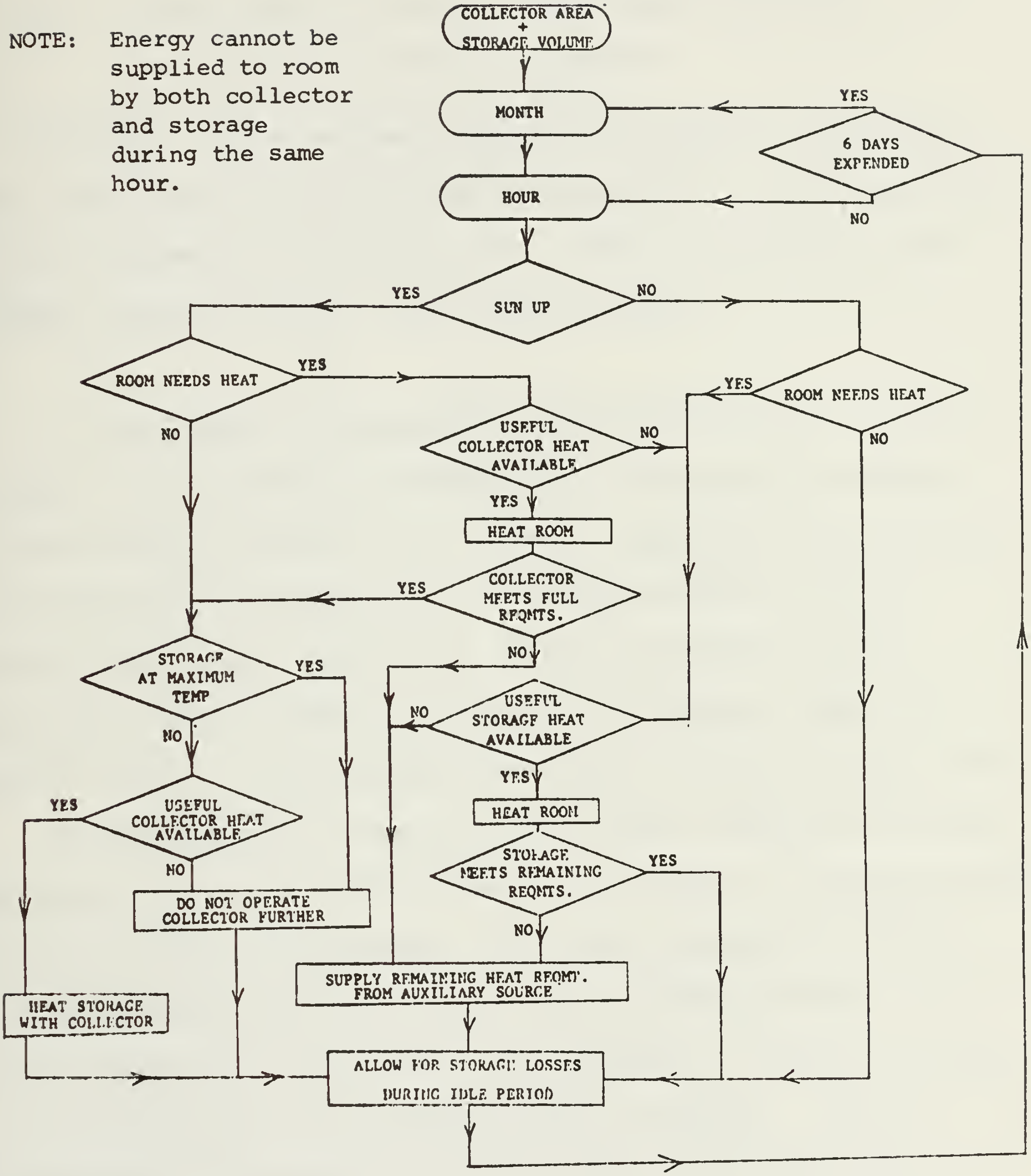


FIGURE 4 Flow Diagram of Overall Simulation Logic (Refer also to Figure A.2)

f. Total useful thermal energy obtaining from the collector for all purposes.

The only temperatures monitored or used as controlling input are those of the storage bed segments. The temperature of the residence is assumed at all times to be within the comfort range in effect for a given season.

To implement the insolation representation of Liu and Jordan [5], it has been assumed that the monthly average of the hourly insolation and ambient temperature applied for one 24-hour period predicts the system behavior for the entire month when the results of this "average" day are multiplied by the number of days in the month. Butz [4] used a similar extrapolation with hourly Weather Bureau data.

A discontinuity occurs in the system operation in going from one month into another due to the change in these monthly average values. Furthermore, the final temperature profile in the storage bed carries into the succeeding month. For these reasons the first days of operation in any given month do not represent a true average daily response. If the simulation is operated for several days utilizing the insolation and ambient temperature profiles of that month, the influence of the starting conditions is eliminated. A

measure of the degree to which the starting conditions have been obscured is the correspondence between storage bed temperature profiles separated by 24 hours of operation.

For the ranges of parameters and values of constants used here, 4 to 5 days operation served to damp out starting effects in most cases. Therefore, the following strategy was used:

i. For each month, 9 full days of hourly operation were simulated.

ii. The last run (corresponding to the 9th day) is used as the "average" day. The results obtained for this day are multiplied by the number of days remaining in the month.

iii. The results for the entire month are obtained by adding the cumulative results of the first 9 days to those obtained in (ii).

During the heating season, the maximum allowable average temperature of the storage bed is chosen to be 145°F. In the limit, then, this is the highest possible forced-air temperature which can be derived from storage. This temperature is at least 20°F below that which outlets from a conventional forced-hot-air heating unit where common practice indicates a rise in temperature of 100°F or more

through the furnace [8]. This lower operating temperature allows more efficient operation of the collector but requires a higher-than-conventional mass flow rate of warm air into the room. The codes [8] restrict the rate of room air change-out and must be consulted. If upon supplying the hourly room needs the collector is able to bring storage to this temperature, the collector ceases to operate. Subsequent collector-to-storage operation is only to the extent necessary to maintain this temperature in the face of demands made upon storage. This mode of operation causes the low usefulness ratios (useful heat collected/incident thermal energy) in early fall and late spring.

During the summer months when this simulation does not supply solar space heating, the maximum storage temperature is allowed to be 180°F for the purpose of domestic water heating. Higher temperatures are possible if pressure relief and mixing values are used in the water system but then the collector would operate less efficiently. 180°F was chosen to avoid unnecessary complication. No attempt is made to model a realistic daily hot water usage scenario in the summer. Instead, the heating load presented to the bed is that of an increased convective heat loss coefficient corresponding approximately to an 80 gal/day draw-down of 100°F water spread evenly through the 24-hour day, added to the previously used

coefficient. Accurate assessment of the water heating mode does not contribute to the objective of this study; this portion of the simulation is included only for continuity.

If the collector can heat the dwelling directly but is unable to meet the full requirement, auxiliary heat is used to make up the deficit. In this situation the only contribution from storage is the uncontrolled convective loss. This strategy is used in order to obtain all the useful solar energy available and does not consider the electrical energy required by the circulation fan to obtain this marginal amount of thermal energy.

Several arbitrary choices have been made as to what constitutes a desirable system operation.

i. If when heating storage with the collector the increase in average bed temperature corresponds to a thermal energy input of less than 3.3 W-hr in one minute (an hourly rate of 200 W), the system is not operated.

ii. When heating the room from storage a 1% overshoot of the room's needs is tolerated. The overshoot shows up as excess heat which is subtracted from the otherwise useful energy gain of the system and results from the time step used (see iv).

iii. If at any time while heating the room from storage the thermal energy added in one minute is less than 5% of 1/60th the total hourly room need, then the system is relaxed and the auxiliary source provides the remainder of the heat load.

iv. All heat transfers to and from storage are accomplished in 1-minute intervals. If some fraction of a minute over the hour is used or an unacceptably large overshoot in energy input occurs, the 1-minute interval in which this occurred is nullified and the process continues in 5-second intervals. Any further overshoot resulting during such a reduced interval is accepted and appears as an accountable excess.

When heating storage from the collector, the inlet temperature to the collector is held fixed for the duration of the hour at its value at the beginning of the hour. In fact this temperature increases as the bed is heated and, if strictly accounted for, could result in a decrease in useable thermal energy available to storage. Errors due to this assumption are considered small considering the small change in temperature of the storage bed which occurs

in one hour. So, in the interest of decreasing computation time, the effect was neglected.

V. RESULTS

Figure 5 demonstrates the ability of various collector sizes to meet the heating demands of the residence used in this simulation. As collector size increases a greater proportion of the room needs can be accommodated. If analysis of cost tradeoffs and regional weather characteristics indicate that it is advantageous to use solar power for approximately half the residential heating needs in mid-winter, then this figure indicates that the 60 m^2 collector should be employed.

The curves of the ratio of solar energy obtained to room needs for various collector sizes were derived using a fixed storage volume. Figure 6 indicates, however, that mid-winter system capability for various collectors is relatively insensitive to the size of storage. The reason for this result is that for the collector sizes examined, no collector provides on a daily basis more energy than the residence consumes in that time. There is then no net accumulation of energy in storage and the total of the daily solar energy obtained reflects the room needs only.

The uppermost, flat curve of Figure 5 represents the practical limit of system output. Achieving this output requires a collector of such size that storage is

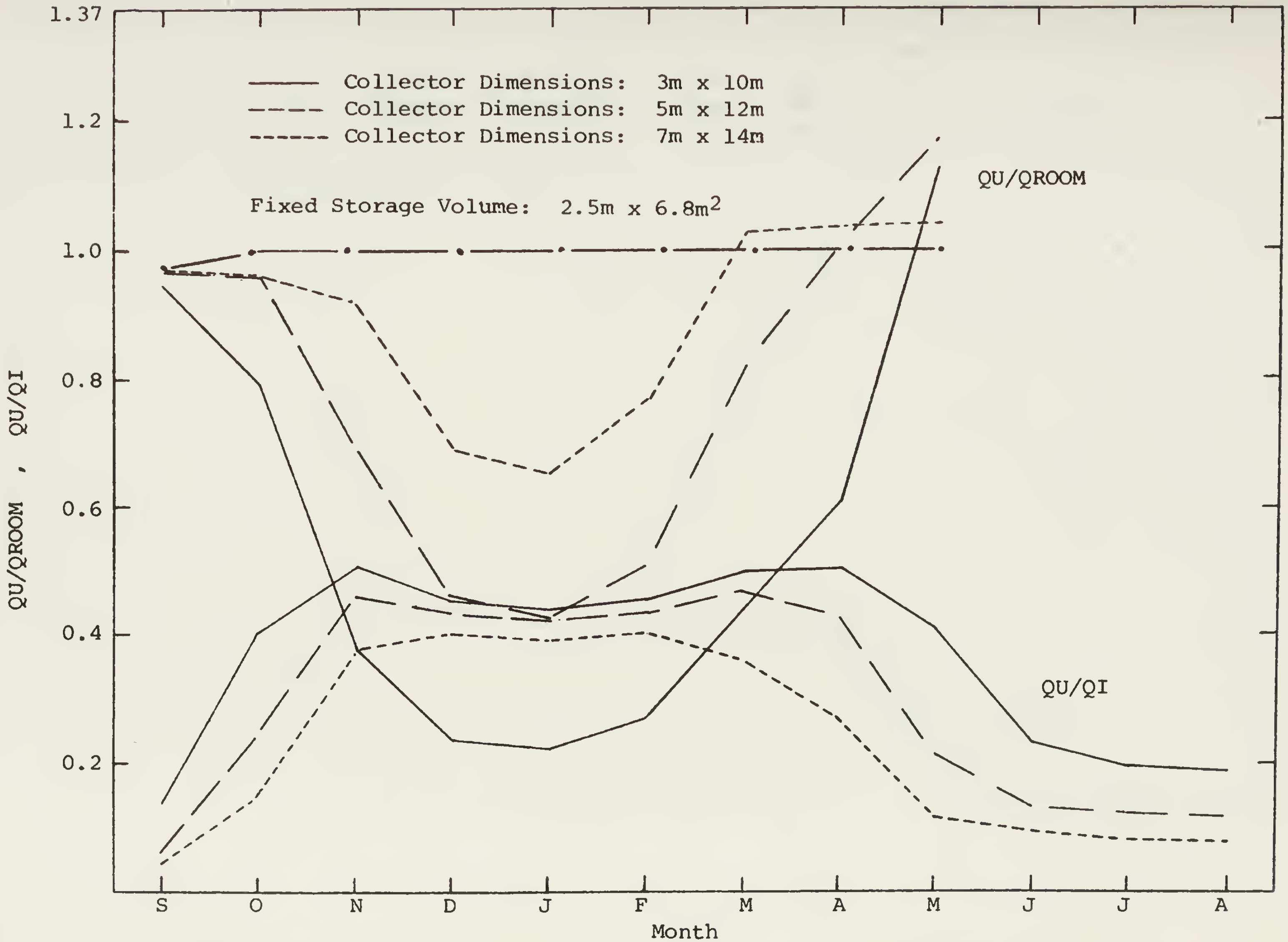


FIGURE 5 Daily Integrated Energy Ratios, Averaged by Months for Fixed Storage Volume

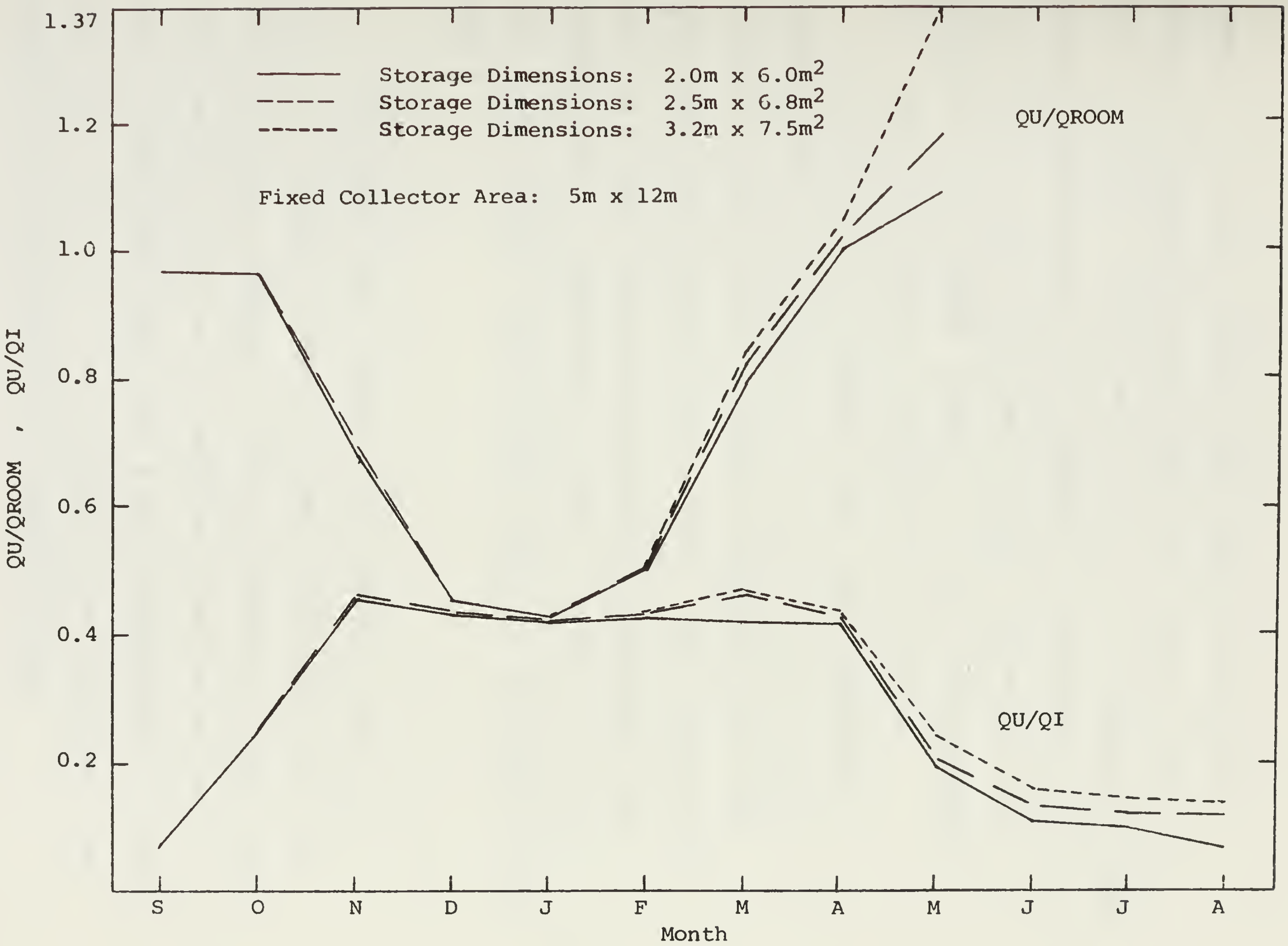


FIGURE 6 Daily Integrated Energy Ratios, Averaged by Months for Fixed Collector Area

brought to a fully charged state each day while the immediate daytime dwelling heat load is met as well. A "fully charged" storage bed is one at the maximum allowable average temperature. It is assumed in presenting this limiting case that sufficient storage volume has been assigned to the system to meet, in full, the overnight heat load if the bed is initially fully charged.

In Figure 5 the QU/QROOM curve (see SIMULATION NOMENCLATURE for definition of terms) for the largest collector used is seen to behave differently than the other two curves during April and May. The "cross over" observed results when the storage bed approaches the maximum average temperature allowed. When this occurs, very little further solar energy input to the system takes place.

A QU/QROOM ratio exceeding the maximum practical value of 1 is seen to occur in late spring for all three collector sizes examined. This is because in those months enough solar energy can be obtained from the collector to meet the room needs <u>and</u> allow a net accumulation of energy in storage. Note that as collector size increases, the QU/QROOM curve approaches the limiting curve.

The curves of QU/QI of Figures 5 and 6 represent the ratio of solar energy collected to that incident upon the tilted collector surface. This ratio is a measure of collection efficiency. For fixed system mass flow rate of air and storage size, increasing collector area decreases collection efficiency because of the higher mean temperature of collection and storage (even if panels are added in parallel).

Efficiency is generally lower in early fall and late spring because the higher insolation and storage temperature approaching saturation cause a higher mean temperature of collection. This, in turn, drives a higher loss rate to the surroundings despite relatively warm ambient temperatures. In late fall and early spring the relation between ambient temperature, available insolation and the lower average temperature in storage combine advantageously to produce the highest efficiency. In mid-winter the low ambient temperature drives large collector losses despite the rather low mean temperature of collection (resulting from the lowest insolation and storage temperature levels of the year).

In Figure 6, the higher efficiency of larger storage beds in spring reflects the increasing level of collector-to-storage heating activity and lower collection temperatures which result from distributing about the same amount of collected energy throughout a larger mass of rock. The approach saturation which will occur as storage size decreases, rapidly increases the efficiency disparity.

Figures 7 and 8 illustrate the monthly totals of hourly solar energy supplied by the system in excess of that required. During early spring and late fall the excess is primarily caused by the uncontrolled convective storage loss. During the winter when all the storage loss is of use to the dwelling, any excess occuring is caused by an "overshoot" of storage energy input to the room during active heating with storage. This overshoot results from the time increment used in the simulation (see pg. 50 Sec. IV) and is not a characteristic of solar systems.

The excess in spring and fall is a real effect if storage is contained within the dwelling. These losses are annoying and are counterproductive to any air-conditioning employed during the day.

All three curves of Figures 7 and 8 extend to about $1.4(10)^5$ W-HR in September, off the scale presented. This occurs because storage was taken to be fully charged at the commencement of this month. The high convective heat losses which are a consequence cause the high excess energy value.

Such excesses do not occur in May because storage temperature levels do not naturally reach saturation with the available solar energy and room requirements

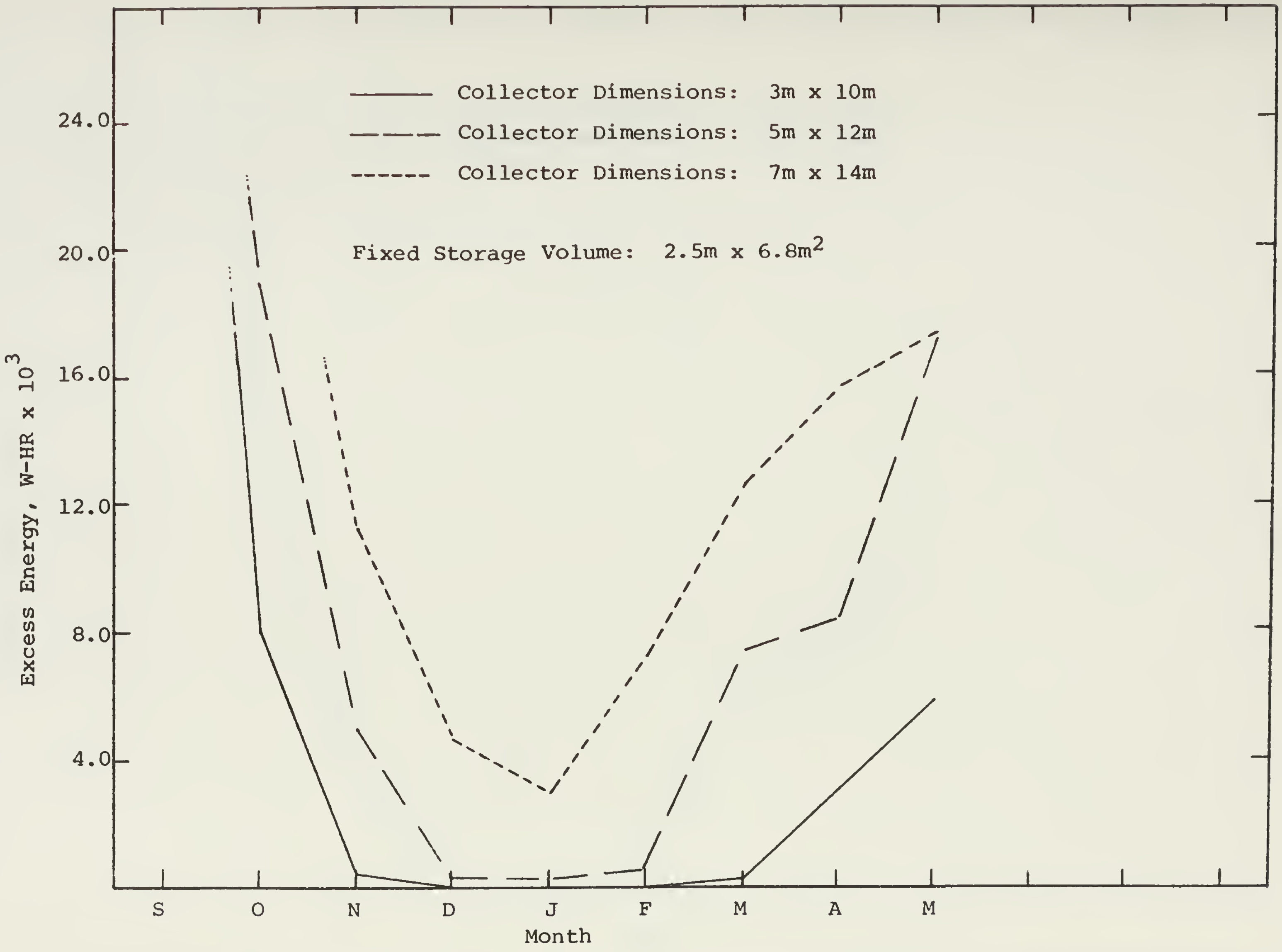


FIGURE 7 Monthly Quantity of Excess Energy, Average by Months, for Fixed Storage Volume

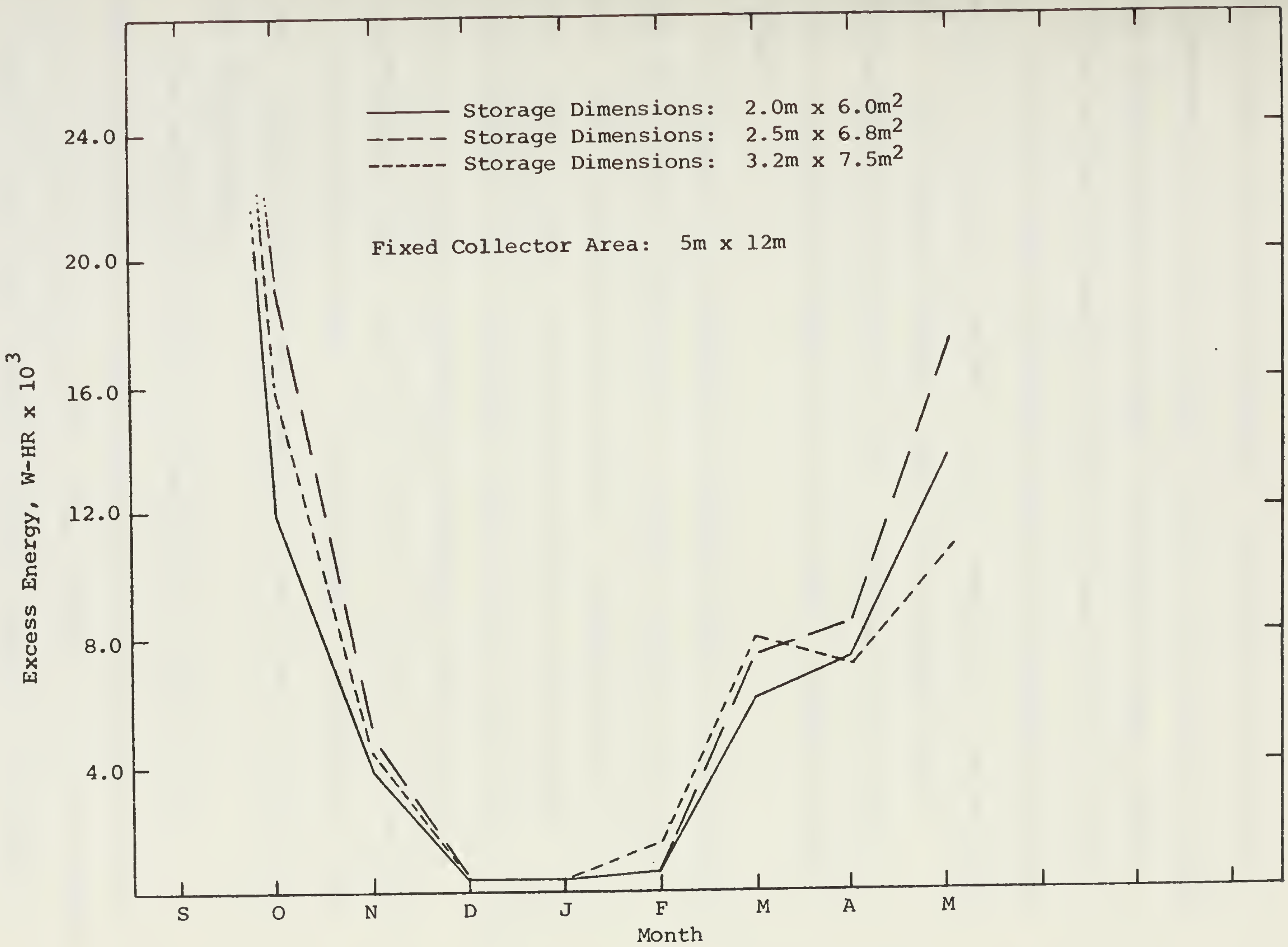


FIGURE 8 Monthly Quantity of Excess Energy, Average by Months, for Fixed Collector Area

are higher in May than September. Starting the month of September with a fully charged storage bed simulates having used storage during the summer for domestic water heating at the maximum allowable average bed temperature of 180°F

The two larger collectors are seen to provide similar amounts of energy in excess of that needed for the month of May. This results because, again, the storage bed is approaching the saturation level. Once near or at this level, a larger collector will not result in more storage losses.

In Figure 8, an apparent anomoly occurs in late spring when the excess energy for the largest storage unit falls below that of the other two units. An examination of the hour-by-hour energy transfers to the room from storage indicates that the "overshoot" flaw is the cause (see pg. 50, Sec. iv). A lesser percentage of excess energy input to the dwelling occurs each hour with the largest bed compared to the two smaller units. This behavior is evidence of the lower overall storage temperature as bed size increases, all else being equal.

The arbitrary choice of storage size used in this simulation happens to span the range over which an inversion occurs in excess energy output from storage. It is observed in Figure 8 that from October through December the excess

energy first increases with increasing storage volume then decreases. Again, inspection of hour-by-hour energy transfers indicates the cause. The smallest bed can provide, in the first several hours after sundown, more hourly energy output than larger units which have a lower average temperature. This is so despite the fact that all beds contain about the same total stored energy.

The higher hourly output from the smallest storage bed results in more hourly overshoot. But since this bed is depleted sooner, it is less often able to provide heat. The cumulative overshoot is consequently less than for larger units.

The largest unit operates to heat the room the most number of times, but each time the overshoot is small because of the relatively lower temperature of the energy provided. Cumulatively, less total overshoot occurs than with the mid-size bed but more than that occurring with the smallest.

Figure 9 shows the degree in which room energy needs are met with the desired collector and various storage volumes. This figure applies to the New York area for September and October starting with a storage bed at room temperature. For the collector size and residence of this example, the only months during which more solar energy is provided than

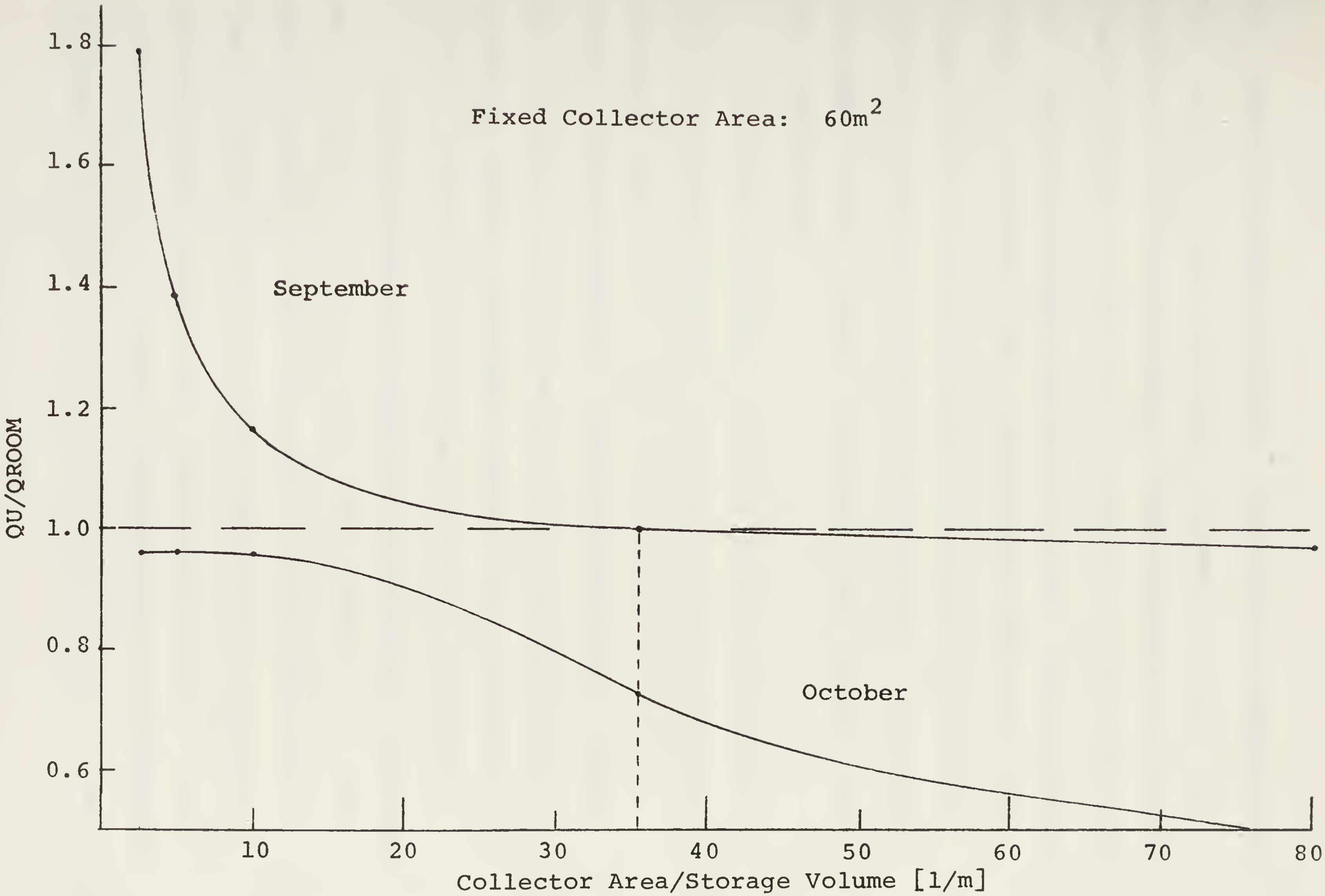


FIGURE 9 Ability of Various Storage-Collector Combinations to Meet Room Heating Needs

that required to meet the daily room needs is September and May. Either of these months may be used to "sense" the presence of the storage bed, no longer masked by the overpowering effect of room needs. Relative stroage size plays very little role during mid-winter because then storage only serves to distribute solar energy stored during the day through part of the immediately following night with no carry-over of energy into the following day. It is clear that <u>some</u> storage volume is necessary but that size has yet to be determined.

The dashed, vertical line of Figure 9 indicates the collector-to-storage ratio for which no more solar energy is collected daily by the system than is required for an average day in September. Allowing nothing for "cloudy days" carry-over storage capability, this system should have a storage volume in September equal to the collector area times the factor 1/35 (the dimensions being in meters).

A storage sizing criterion which optimizes mid-winter use of the solar heating system would seem to be a more rational criterion than the above. It has been shown, however, that mid-winter system operation is relatively insensitive to storage size. Within the range of storage sizes examined, the ratio of storage output to room needs increases less than 1% (see Table 4) when storage volume increases

twofold. So, such a criterion is elusive at best. Intuitively, there are limits to the range of useful storage temperatures and this suggests an upper and lower bound to storage volume exists.

If an upper temperature limit is placed on the bed (as dictated by the codes as regards delivery temperature or room air change-out rate, etc.: in this simulation 145° F was used) there is a lower storage volume which will attain, on average, this saturation temperature using <u>all</u> the energy available <u>to storage</u> on a typical mid-winter day. However, because the collector operates inefficiently due to the high temperature it receives from storage, the total energy stored is less than could have been obtained for any larger storage bed given the same conditions.

The lower limit on storage bed temperature is that which provides a comfortable influx of heating air and depends on relative humidity. Generally, normal body temperature represents a good estimate of this lower limit on storage temperature. The storage volume for which this temperature obtains when <u>all</u> the energy available <u>to storage</u> on a mid-winter day is accepted, is the upper limit on storage volume. This provides the most efficient system operation based on collected energy but the energy stored at this temperature is only marginally useful.

Lacking a definitive mid-winter storage-sizing method, it is suggested that the "September storage sizing criterion" above be adopted as a method of determining storage volume given a collector area.

In this simulation, using a 5m x 12m collector the storage volume thus indicated is $1.7m^3$. If it is assumed that the energy available to storage in January for a $6.8m^2 \times 2.5m$ storage volume (see Table A.1) remains constant as the storage volume decreases to $1.7m^3$, the resulting average storage bed temperature attains 115°F (if it starts at room temperature). Of course, due to collector inefficiency the collected energy would be less as would be the temperature attained.

Thus, an even smaller storage bed could be used without saturation occurring but less total energy would be stored.

TABLE 4

Energy input to room from storage, between sunrise and sunset, as a percentage of room needs during that period. Values are for January with combinations of storage and collector sizes as indicated.

Collector Area (m^2)	Storage Volume (m^3) 12	17	24
30		0.3%	
60	22.9%	23.6%	23.8%
98		57.9%	

VI. CONCLUSIONS

From Figures 5 and 6 it can be concluded that collector area requirements to meet a known energy need can be determined without regard to storage size.

It is unnecessary to consider increasing storage size to allow for the "carry over" of solar energy into subsequent "cloudy days" because for economically sized collector areas designed for mid-winter needs there is, on the average, no energy available for subsequent days. Only if more than 100% of the daily room requirements can be supplied from the system in mid-winter is there, on the average, a "carry over" capability which can be enhanced by increasing storage size. Collector size is the single most important consideration in installing this solar heating system.

Once the collector area necessary to meet the energy need has been determined a compatible storage volume must be derived. "Compatible storage volume" is taken to be that volume which results in a QU/QROOM ratio of 1 in September (see Figure 9). It must be realized that such compatability of collector and storage applies only to a system providing approximately 50% of the mid-winter

space heating requirement and the location for which this analysis was carried out, that is, New York.

Within the above conditions, it is suggested that the ratio 35:1 be used to relate collector area to storage volume (dimensions in meters) for a hot air system with pebble bed storage. Researchers generally quote suggested ratios of collector size per storage volume (or per person for strictly domestic water heating applications) when speaking of water-type systems. When doing so, the validity of the ratio is predicated on specifying the location and percentage to be met of the total demand. It is for this reason, with a similar claim of validity, that the ratio above is presented.

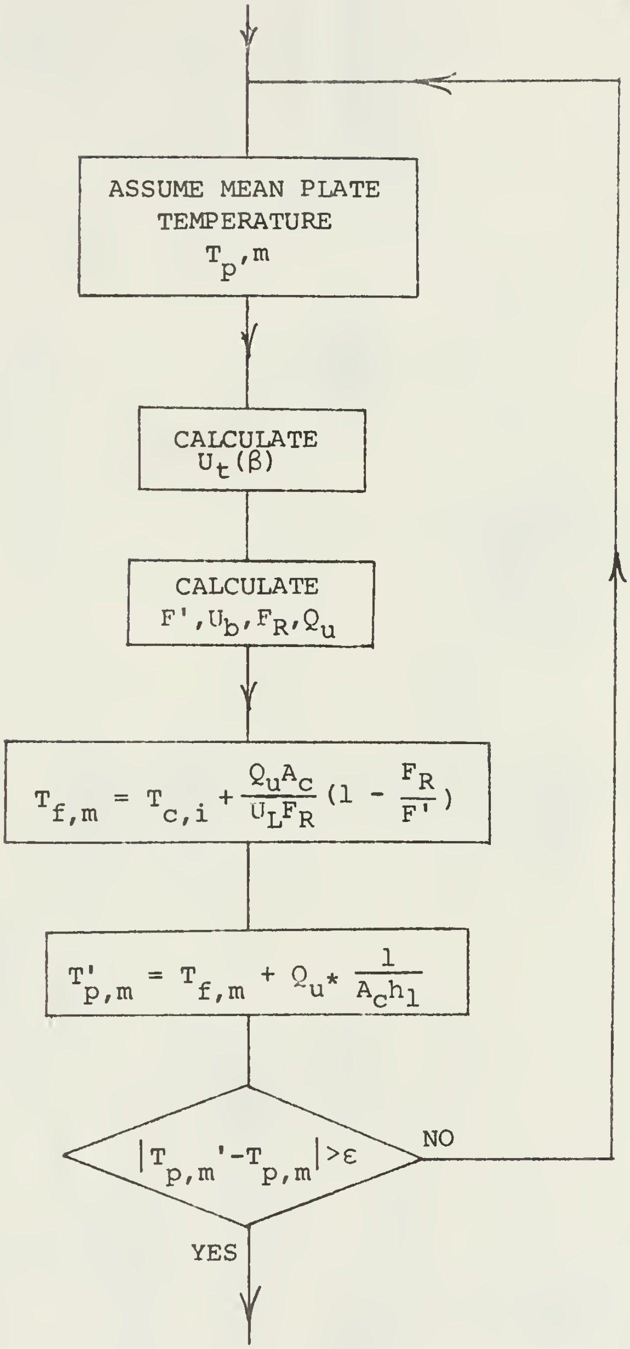
APPENDIX

The flow chart included here illustrates the simulation of the solar heating system used in this study.

The numbers appearing in the chart are keyed to the various "go to" statements used in the computer program and are included in order to guide the reader through the computer listing appended.

The terms used herein are defined in the SIMULATION NOMENCLATURE section of the appendix.

Two pages of output are presented to illustrate their form.



ε = error

FIGURE A.1. Determining the Mean Plate Temperature [1]

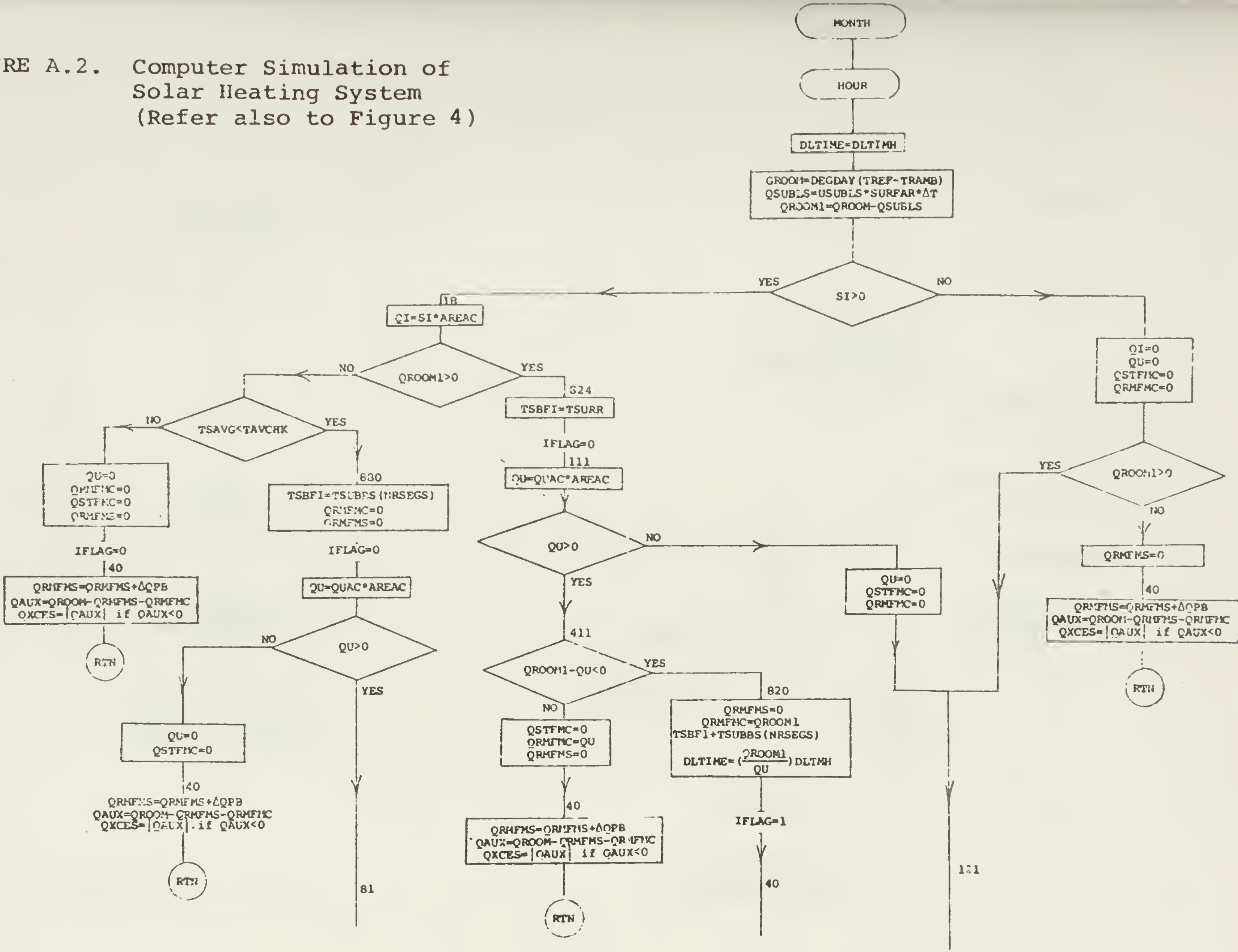


FIGURE A.2. Computer Simulation of Solar Heating System (Refer also to Figure 4)

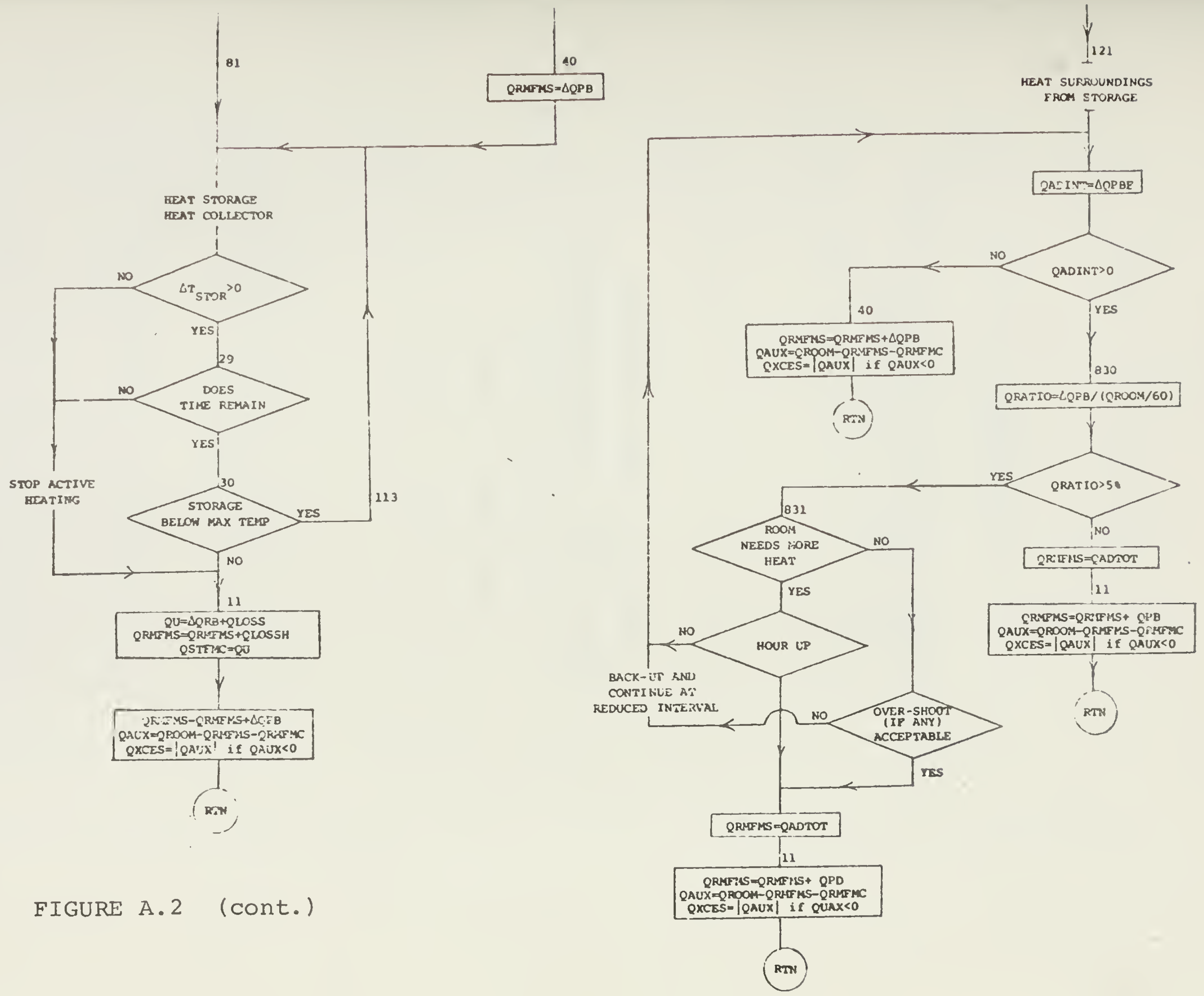


FIGURE A.2 (cont.)

TABLE A.1

Sample of Yearly Simulation Output for an Average Day in Each Month

Collector Area: 5m x 12m

Storage Volume: $6.8m^2$ x 2.5m

Temperatures in °C

Hours are Solar Time

SEPTEMBER

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	14.45	0.0	0.0	1450.3	0.0	1450.6	0.0	0.0	458.3
1- 2	14.56	0.0	0.0	1409.5	0.0	1448.9	0.0	0.0	456.0
2- 3	14.88	0.0	0.0	1289.7	0.0	1367.2	0.0	0.0	453.7
3- 4	15.33	0.0	0.0	1097.8	0.0	1125.3	0.0	0.0	451.6
4- 5	16.07	0.0	0.0	844.8	0.0	883.1	0.0	0.0	449.8
5- 6	16.87	0.0	0.0	545.6	0.0	561.7	0.0	0.0	448.5
6- 7	17.75	4611.7	837.2	1257.3	837.2	418.6	0.0	1.4	418.7
7- 8	18.65	13438.0	501.3	919.4	501.3	417.8	0.0	0.3	418.1
8- 9	19.53	21446.2	1670.8	591.3	173.9	419.0	1496.9	0.0	417.4
9-10	20.33	27944.2	6315.4	0.0	0.0	424.3	6315.4	0.0	419.1
10-11	21.01	32538.9	8996.0	0.0	0.0	435.8	8996.0	0.0	428.3
11-12	21.52	34917.2	0.0	0.0	0.0	441.9	0.0	0.0	441.7
12-13	21.84	34917.2	401.7	0.0	0.0	441.7	401.7	0.0	441.0
13-14	21.95	32538.9	532.6	0.0	0.0	441.8	532.6	0.0	440.9
14-15	21.84	27944.1	388.5	0.0	0.0	441.5	388.5	0.0	441.1
15-16	21.52	21446.2	436.1	0.0	0.0	441.6	436.1	0.0	441.0
16-17	21.01	13487.9	0.0	0.0	0.0	440.8	0.0	0.0	441.0
17-18	20.33	4611.7	0.0	0.0	0.0	440.3	0.0	0.0	440.3
18-19	19.53	0.0	0.0	591.3	0.0	609.2	0.0	0.0	439.6
19-20	18.65	0.0	0.0	919.4	0.0	990.3	0.0	0.0	438.7
20-21	17.75	0.0	0.0	1257.3	0.0	1293.9	0.0	0.0	437.1
21-22	16.87	0.0	0.0	1585.4	0.0	1596.1	0.0	0.0	435.1
22-23	16.07	0.0	0.0	844.8	0.0	886.9	0.0	0.0	461.4
23-24	15.39	0.0	0.0	1097.8	0.0	1128.9	0.0	0.0	460.0
MONTHLY TOTALS		8096757.0	587668.9	471048.1	45306.5	556531.6	542362.4	48.4	317458.6

QXCSMT= 1.30839E 05 QUQRM = 0.96982 QUQI = 7.25808E-02 QAXQRM= 1.02739E-04 QSLRQR= 0.99990

SEPTEMBER

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	64.771	63.096	62.012	60.570	52.444
7- 8	64.701	63.029	61.947	60.506	52.394
8- 9	64.632	62.962	61.882	60.444	52.344
9-10	61.166	62.746	62.283	61.091	55.789
10-11	62.167	62.150	62.243	61.767	59.184
11-12	65.484	63.319	62.459	62.019	60.695
12-13	65.413	63.252	62.384	61.953	60.622
13-14	65.496	63.252	62.346	61.902	60.599
14-15	65.599	63.289	62.323	61.857	60.594
15-16	65.591	63.326	62.303	61.814	60.588
16-17	65.266	63.501	62.370	61.813	60.669
17-18	65.135	63.433	62.304	61.748	60.605
18-19	65.126	63.365	62.238	61.683	60.542
19-20	65.107	63.353	62.231	61.664	60.140
20-21	65.077	63.334	62.221	61.529	59.490
21-22	65.038	63.308	62.205	61.567	58.657
22-23	64.990	63.277	62.185	61.468	57.653
23-24	64.965	63.261	62.173	61.404	57.102
0- 1	64.934	63.241	62.157	61.317	56.407
1- 2	64.894	63.214	62.134	61.189	55.533
2- 3	64.854	63.188	62.108	61.044	54.679
3- 4	64.816	63.163	62.082	60.894	53.889
4- 5	64.786	63.142	62.057	60.760	53.251
5- 6	64.762	63.126	62.036	60.647	52.760

OCTOBER

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	7.40	0.0	0.0	4087.7	0.0	4153.3	0.0	0.0	436.7
1- 2	7.54	0.0	0.0	4034.0	0.0	4068.3	0.0	0.0	430.2
2- 3	7.97	0.0	0.0	3875.7	0.0	3903.6	0.0	0.0	423.8
3- 4	8.65	0.0	0.0	3622.2	0.0	3659.2	0.0	0.0	417.7
4- 5	9.54	0.0	0.0	3288.1	0.0	3336.7	0.0	0.0	412.0
5- 6	10.59	0.0	0.0	2893.0	0.0	2935.8	0.0	0.0	406.7
6- 7	11.75	4294.3	0.0	3499.4	0.0	3505.0	0.0	0.0	373.2
7- 8	12.95	12978.4	2733.3	3053.1	2685.4	367.3	47.9	0.5	367.7
8- 9	14.11	20764.4	3847.9	2619.8	2252.6	368.6	1595.3	0.0	367.2
9-10	15.16	27121.7	6552.6	2224.6	1855.5	373.2	4697.1	0.0	369.1
10-11	16.05	31616.9	9425.8	1890.6	1514.7	382.3	7911.2	0.0	375.9
11-12	16.73	33943.8	11351.1	1637.1	1249.4	394.8	10101.7	0.0	387.7
12-13	17.16	33943.8	11680.3	1478.8	1075.9	410.5	10604.4	0.0	402.9
13-14	17.30	31616.9	10231.0	1425.0	1006.2	425.3	9224.8	0.0	418.8
14-15	17.16	27121.6	7212.9	1478.8	1046.2	436.7	6166.7	0.0	432.6
15-16	16.73	20764.4	1286.6	1637.1	1195.5	441.4	91.1	0.2	441.5
16-17	16.05	12978.4	1449.6	1890.6	1449.6	440.8	0.0	0.2	441.0
17-18	15.16	4294.3	61.4	2224.6	61.4	440.3	0.0	1722.9	440.3
18-19	14.11	0.0	0.0	2619.8	0.0	2644.4	0.0	0.0	439.6
19-20	12.95	0.0	0.0	3053.1	0.0	3096.1	0.0	0.0	435.5
20-21	11.75	0.0	0.0	3499.4	0.0	3546.4	0.0	0.0	430.6
21-22	10.59	0.0	0.0	3932.7	0.0	3995.8	0.0	0.0	425.1
22-23	9.54	0.0	0.0	3288.1	0.0	3361.4	0.0	0.0	447.7
23-24	8.65	0.0	0.0	3622.2	0.0	3678.1	0.0	0.0	442.4
MONTHLY TOTALS		8104598.0	2011296.0	2073133.0	476864.5	1561816.0	1534431.0	53435.0	309284.8

@
QXCSMT= 18984. QUQRM = 0.96102 QUQI = 0.24817 QAXQRM= 2.57750E-02 QSLRQR= 0.97423

OCTOBER

HOUR	STORAGE STREAM TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	64.237	63.064	60.420	54.158	39.163
7- 8	64.153	62.494	60.023	53.249	36.023
8- 9	62.284	62.453	60.085	53.502	38.680
9-10	56.910	61.695	60.763	55.747	43.867
10-11	54.384	58.134	60.079	58.357	51.334
11-12	57.373	57.277	58.497	59.741	55.469
12-13	62.172	59.188	58.307	58.411	57.169
13-14	64.506	61.349	59.665	59.711	57.911
14-15	65.625	63.815	61.584	59.860	58.684
15-16	65.030	64.565	63.122	61.343	59.893
16-17	64.772	64.527	63.099	61.333	59.788
17-18	64.862	64.455	63.032	61.268	59.726
18-19	64.733	64.389	62.965	61.204	59.665
19-20	64.713	64.322	62.883	61.085	57.962
20-21	64.687	64.242	62.782	60.864	56.058
21-22	64.654	64.149	62.655	60.509	53.995
22-23	64.612	64.042	62.492	59.998	51.810
23-24	64.575	63.953	62.344	59.514	50.035
0- 1	64.533	63.852	62.160	58.911	48.198
1- 2	64.480	63.730	61.920	58.151	46.245
2- 3	64.423	63.603	61.650	57.337	44.449
3- 4	64.365	63.471	61.357	56.501	42.822
4- 5	64.305	63.336	61.051	55.676	41.399
5- 6	64.247	63.205	60.745	54.896	40.163

NOVEMBER

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	-0.44	0.0	0.0	7021.8	0.0	4733.2	0.0	2288.5	25.0
1- 2	-0.29	0.0	0.0	6962.6	0.0	3657.1	0.0	3305.5	17.6
2- 3	0.18	0.0	0.0	6788.5	0.0	2678.5	0.0	4110.0	11.9
3- 4	0.92	0.0	0.0	6509.6	0.0	1855.1	0.0	4654.6	7.7
4- 5	1.91	0.0	0.0	6142.2	0.0	1219.7	0.0	4922.5	4.8
5- 6	3.07	0.0	0.0	5707.5	0.0	766.0	0.0	4941.5	2.9
6- 7	4.34	2625.7	0.0	6270.6	0.0	-27.1	0.0	6297.7	-27.1
7- 8	5.66	9551.5	2337.2	5779.7	2337.2	-27.0	0.0	3469.6	-27.1
8- 9	6.93	15761.1	7050.1	5303.0	5330.1	-26.7	1720.0	0.0	-27.1
9-10	8.09	20831.2	10740.4	4868.4	4892.7	-21.8	5847.7	0.0	-24.3
10-11	9.08	24416.3	13140.2	4500.9	4516.1	-10.6	8624.2	0.0	-15.1
11-12	9.82	26272.0	14284.6	4222.0	4223.7	4.0	10060.9	0.0	-1.6
12-13	10.29	26272.1	14161.4	4048.0	4033.9	19.9	10127.6	0.0	14.1
13-14	10.44	24416.3	12844.5	3988.8	3958.9	34.9	8885.6	0.0	29.9
14-15	10.29	20831.1	10435.4	4048.0	4004.2	47.0	6431.2	0.0	43.8
15-16	9.82	15761.1	7137.1	4222.0	4168.3	54.7	2968.8	0.0	53.7
16-17	9.08	9551.5	2955.6	4500.9	2955.6	58.3	0.0	1487.0	58.3
17-18	8.09	2625.6	0.0	4868.4	0.0	4875.9	0.0	0.0	58.2
18-19	6.93	0.0	0.0	5303.0	0.0	5307.3	0.0	0.0	50.6
19-20	5.66	0.0	0.0	5779.7	0.0	5780.3	0.0	0.0	42.3
20-21	4.34	0.0	0.0	6270.6	0.0	6306.0	0.0	0.0	33.2
21-22	3.07	0.0	0.0	6747.2	0.0	5282.6	0.0	1464.7	23.4
22-23	1.91	0.0	0.0	6142.2	0.0	6201.8	0.0	0.0	43.9
23-24	0.92	0.0	0.0	6509.6	0.0	5897.1	0.0	612.5	34.2
MONTHLY TOTALS		5967455.0	2753718.0	3975145.0	1205336.0	1804346.0	1548383.0	970435.8	33248.3

QXCSMT= 4963.7 QUQRM = 0.69149 QUQI = 0.46146 QAXQRM= 0.24413 QSLRQR= 0.75587

NOVEMBER

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	17.[illegible]	17.720	17.577	17.519	17.503
7- 8	17.[illegible]	17.724	17.581	17.523	17.507
8- 9	17.9[illegible]	17.728	17.565	17.528	17.511
9-10	19.[illegible]72	17.896	17.630	17.546	17.520
10-11	21.[illegible]55	19.003	17.943	17.635	17.548
11-12	24.[illegible]95	21.109	18.924	17.994	17.665
12-13	27.182	23.534	20.597	18.856	18.030
13-14	2[illegible].527	25.659	22.588	20.220	19.776
14-15	2[illegible].11[illegible]	27.168	24.446	21.829	19.873
15-16	2[illegible].[illegible]5	27.[illegible]1	25.944	23.321	21.091
16-17	2[illegible].371	2[illegible].1[illegible]7	26.589	24.289	22.002
17-18	2[illegible].35[illegible]	2[illegible].175	26.578	24.243	22.000
18-19	28.12[illegible]	27.375	25.536	23.311	21.369
19-20	27.[illegible]95	26.371	24.421	22.414	20.925
20-21	26.[illegible]	25.149	23.209	21.633	20.622
21-22	25.354	23.711	22.132	20.958	20.428
22-23	23.[illegible]16	22.461	21.311	20.622	20.337
23-24	22.85[illegible]	21.659	20.743	19.928	18.798
0- 1	21.[illegible]4[illegible]	20.823	19.902	18.945	18.018
1- 2	2[illegible].[illegible]	19.977	19.076	18.270	17.709
2- 3	20.[illegible]	19.209	18.450	17.386	17.584
3- 4	19.342	18.602	18.037	17.686	17.534
4- 5	18.741	18.172	17.790	17.588	17.514
5- 6	18.297	17.891	17.651	17.541	17.506

DECEMBER

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	-5.44	0.0	0.0	8891.8	0.0	2953.4	0.0	5938.4	17.3
1- 2	-5.29	0.0	0.0	8832.6	0.0	2464.3	0.0	6368.3	12.7
2- 3	-4.82	0.0	0.0	8658.5	0.0	1908.5	0.0	6750.0	8.9
3- 4	-4.08	0.0	0.0	8379.6	0.0	1374.3	0.0	7005.4	5.9
4- 5	-3.09	0.0	0.0	8012.2	0.0	800.3	0.0	7211.8	3.7
5- 6	-1.93	0.0	0.0	7577.5	0.0	92.9	0.0	7484.6	2.5
6- 7	-0.66	2322.7	0.0	8140.6	0.0	-26.4	0.0	8167.0	-26.5
7- 8	0.66	8877.1	1197.3	7649.7	1197.3	-26.4	0.0	6478.8	-26.5
8- 9	1.93	14753.8	5547.9	7173.0	5547.9	-25.4	0.0	1651.5	-26.4
9-10	3.09	19552.0	9019.7	6738.4	6764.7	-25.8	2255.0	0.0	-26.4
10-11	4.08	22944.9	11377.4	6370.9	6393.7	-21.0	4983.7	0.0	-22.8
11-12	4.82	24701.2	12576.6	6092.0	6107.0	-12.3	6469.5	0.0	-15.0
12-13	5.29	24701.2	12626.2	5918.0	5922.8	-2.0	6703.4	0.0	-4.8
13-14	5.44	22944.9	11540.6	5858.8	5853.1	7.9	5687.5	0.0	5.7
14-15	5.29	19552.0	9371.9	5918.0	5903.4	15.5	3468.5	0.0	14.5
15-16	4.82	14753.8	6072.1	6092.0	6072.1	19.9	0.0	0.1	19.9
16-17	4.08	8877.1	1814.9	6370.9	1814.9	19.9	0.0	4536.1	19.9
17-18	3.09	2322.6	0.0	6738.4	0.0	6228.7	0.0	509.7	19.9
18-19	1.93	0.0	0.0	7173.0	0.0	3943.6	0.0	3229.4	10.1
19-20	0.66	0.0	0.0	7649.7	0.0	2086.2	0.0	5563.4	4.0
20-21	-0.66	0.0	0.0	8140.6	0.0	591.2	0.0	7549.4	0.7
21-22	-1.93	0.0	0.0	8617.2	0.0	-0.2	0.0	8617.4	-0.2
22-23	-3.09	0.0	0.0	8012.2	0.0	3845.3	0.0	4166.9	28.6
23-24	-4.08	0.0	0.0	8379.6	0.0	3355.3	0.0	5024.3	22.6
MONTHLY TOTALS		5775395.0	2515510.0	5498925.0	1598889.0	916192.3	916623.6	2984201.0	1486.8

QXCSMT= 345.35 QUQRM = 0.45739 QUQI = 0.43556 QAXQRM= 0.54269 QSLRQR= 0.45731

DECEMBER

HR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	18.127	17.823	17.629	17.536	17.505
7- 8	18.130	17.827	17.633	17.540	17.510
8- 9	18.133	17.830	17.637	17.544	17.514
9-10	18.137	17.834	17.642	17.548	17.518
10-11	19.538	18.050	17.702	17.576	17.531
11-12	21.542	18.367	17.965	17.659	17.561
12-13	24.260	20.583	18.659	17.902	17.643
13-14	25.714	22.311	19.750	18.408	17.841
14-15	26.440	23.586	20.944	19.122	18.160
15-16	26.360	24.446	21.841	19.777	18.547
16-17	26.351	24.440	21.838	19.773	18.550
17-18	26.341	24.433	21.836	19.778	18.553
18-19	24.441	22.344	20.436	19.443	19.592
19-20	22.670	20.993	19.924	19.590	19.995
20-21	21.411	20.328	19.975	19.939	20.163
21-22	20.943	20.157	19.922	20.037	20.207
22-23	20.942	20.157	19.923	20.037	20.207
23-24	20.417	20.012	19.848	19.505	18.589
0- 1	20.094	19.754	19.355	18.703	17.939
1- 2	19.739	19.304	18.757	18.143	17.676
2- 3	19.302	18.709	18.269	17.923	17.571
3- 4	18.543	18.360	17.939	17.656	17.529
4- 5	18.435	18.034	17.739	17.574	17.512
5- 6	18.161	17.845	17.640	17.539	17.506

JANUARY

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	-6.84	0.0	0.0	9414.0	0.0	2775.1	0.0	6638.9	16.3
1- 2	-6.69	0.0	0.0	9358.7	0.0	2312.2	0.0	7046.5	12.0
2- 3	-6.26	0.0	0.0	9195.9	0.0	1795.4	0.0	7400.5	8.4
3- 4	-5.56	0.0	0.0	8935.2	0.0	1297.6	0.0	7637.5	5.6
4- 5	-4.64	0.0	0.0	8591.6	0.0	530.3	0.0	8061.3	3.5
5- 6	-3.56	0.0	0.0	8185.1	0.0	86.1	0.0	8099.0	2.7
6- 7	-2.36	2560.0	0.0	8779.1	0.0	-26.2	0.0	8805.4	-26.2
7- 8	-1.14	9415.5	1104.5	8320.1	1104.5	-26.1	0.0	7241.8	-26.2
8- 9	0.06	15562.0	5632.2	7874.4	5632.2	-26.1	0.0	2268.4	-26.2
9-10	1.14	20580.6	9197.9	7468.0	7494.1	-25.8	1703.8	0.0	-26.1
10-11	2.06	24129.3	11644.7	7124.4	7147.8	-22.0	4496.9	0.0	-23.4
11-12	2.76	25956.3	12884.9	6863.6	5880.0	-14.1	6004.9	0.0	-16.4
12-13	3.19	25966.3	12943.0	6700.9	6707.8	-4.5	6235.2	0.0	-6.9
13-14	3.34	24129.3	11832.7	6645.5	6642.7	4.7	5190.0	0.0	2.8
14-15	3.19	20580.6	9574.3	6700.9	6689.9	11.6	2884.4	0.0	10.9
15-16	2.76	15562.0	6125.9	6863.6	6125.9	15.4	0.0	722.4	15.4
16-17	2.06	9415.5	1682.9	7124.4	1682.9	15.4	0.0	5426.1	15.4
17-18	1.14	2560.0	0.0	7468.0	0.0	5893.1	0.0	1574.8	15.4
18-19	0.06	0.0	0.0	7874.4	0.0	3401.5	0.0	4472.9	6.2
19-20	-1.14	0.0	0.0	8320.1	0.0	1533.1	0.0	6787.1	0.8
20-21	-2.36	0.0	0.0	8779.1	0.0	-1.5	0.0	8780.7	-1.6
21-22	-3.56	0.0	0.0	9224.8	0.0	-1.5	0.0	9226.4	-1.6
22-23	-4.64	0.0	0.0	8591.6	0.0	3795.2	0.0	4796.3	27.3
23-24	-5.56	0.0	0.0	8935.2	0.0	3196.0	0.0	5739.1	21.3
MONTHLY TOTALS		6089250.0	2561313.0	5993482.0	1739339.0	821810.8	821976.6	3432621.0	294.6

QXCSMT= 278.01 QUQRM = 0.42730 QUQI = 0.42063 QAXQRM= 0.57273 QSLRQR= 0.42727

JANUARY

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNINGS OF HOUR INDICATED				
6- 7	18.177	17.363	17.551	17.544	17.577
7- 8	18.181	17.366	17.655	17.548	17.511
8- 9	18.184	17.370	17.660	17.552	17.515
9-10	18.187	17.374	17.664	17.556	17.520
10-11	19.271	18.014	17.708	17.579	17.531
11-12	21.527	18.769	17.906	17.646	17.558
12-13	23.336	20.195	18.456	17.820	17.601
13-14	25.546	21.828	19.378	18.213	17.764
14-15	25.273	23.166	20.416	18.777	18.008
15-16	25.243	23.383	21.157	19.258	18.252
16-17	25.233	23.492	21.156	19.260	18.255
17-18	25.231	23.477	21.154	19.262	18.255
18-19	24.250	21.771	19.934	19.134	19.444
19-20	22.011	20.519	19.524	19.521	19.949
20-21	[illegible]	19.873	19.668	19.852	20.143
21-22	[illegible]	19.780	19.669	19.853	20.144
22-23	[illegible]	19.580	19.670	19.854	20.144
23-24	20.317	19.414	19.669	19.408	19.563
0- 1	19.947	19.592	19.244	18.655	17.928
1- 2	[illegible]	19.190	18.693	18.120	17.672
2- 3	19.102	18.726	18.234	17.812	17.570
3- 4	18.766	18.316	17.921	17.651	17.528
4- 5	18.365	18.308	17.729	17.572	17.512
5- 6	18.227	17.383	17.662	17.547	17.507

FEBRUARY

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	-6.84	0.0	0.0	9414.0	0.0	3184.3	0.0	6229.7	18.5
1- 2	-6.69	0.0	0.0	9358.7	0.0	2645.1	0.0	6713.6	13.5
2- 3	-6.26	0.0	0.0	9195.9	0.0	2035.5	0.0	7160.5	9.4
3- 4	-5.56	0.0	0.0	8935.2	0.0	1457.0	0.0	7478.2	6.2
4- 5	-4.64	0.0	0.0	8591.6	0.0	816.5	0.0	7775.1	3.9
5- 6	-3.56	0.0	0.0	8185.1	0.0	85.8	0.0	8099.3	2.6
6- 7	-2.36	3490.8	0.0	8779.1	0.0	-26.3	0.0	8805.4	-26.3
7- 8	-1.14	11196.7	1773.1	8320.1	1773.1	-26.2	0.0	6573.2	-26.3
8- 9	0.06	18105.6	6896.0	7874.4	6896.0	-26.2	0.0	1004.7	-26.2
9-10	1.14	23746.7	11005.9	7468.0	7494.2	-25.3	3511.7	0.0	-26.2
10-11	2.06	27735.6	13722.3	7124.4	7145.1	-18.1	6577.2	0.0	-20.7
11-12	2.76	29800.3	15085.4	6863.6	6874.0	-6.8	8211.4	0.0	-10.4
12-13	3.19	29800.3	15098.6	6700.9	6698.4	6.2	8400.3	0.0	2.5
13-14	3.34	27735.6	13785.2	6645.5	6629.9	18.6	7155.4	0.0	15.6
14-15	3.19	23746.7	11219.8	6700.9	6674.1	28.3	4545.7	0.0	26.8
15-16	2.76	18105.6	7395.8	6963.6	6829.8	33.8	566.1	0.0	33.9
16-17	2.06	11196.7	2352.6	7124.4	2352.6	34.7	0.0	4737.1	34.7
17-18	1.14	3490.8	0.0	7468.0	0.0	7471.7	0.0	0.0	34.6
18-19	0.06	0.0	0.0	7874.4	0.0	6280.6	0.0	1593.8	23.0
19-20	-1.14	0.0	0.0	8320.1	0.0	4002.4	0.0	4317.8	13.1
20-21	-2.36	0.0	0.0	8779.1	0.0	2295.1	0.0	6484.1	6.9
21-22	-3.56	0.0	0.0	9224.8	0.0	1067.6	0.0	8157.2	3.3
22-23	-4.64	0.0	0.0	8591.6	0.0	4029.5	0.0	4562.1	30.4
23-24	-5.56	0.0	0.0	8935.2	0.0	3604.0	0.0	5331.2	24.1
MONTHLY TOTALS		6386226.0	2753361.0	5413468.0	1662272.0	1091142.0	1091091.0	2660603.0	4677.0

QXCSMT= 538.64 QUQRM = 0.50851 QUQI = 0.43101 QAXQRM= 0.49148 QSLRQR= 0.50852

FEBRUARY

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	17.175	17.346	17.638	17.538	17.506
7- 8	[illegible]	17.350	17.642	17.542	17.510
8- 9	17.181	17.354	17.646	17.547	17.514
9-10	[illegible]	17.358	17.650	17.551	17.519
10-11	[illegible]	18.236	17.745	17.590	17.535
11-12	[illegible]	19.562	18.154	17.713	17.577
12-13	[illegible]	21.646	19.139	18.078	17.791
13-14	27.781	23.766	20.593	18.803	17.998
14-15	[illegible]	25.405	22.130	19.739	18.497
15-16	[illegible]	26.311	23.295	20.707	19.046
16-17	[illegible]	26.425	23.494	20.985	19.166
17-18	[illegible]	26.415	23.499	20.894	19.167
18-19	[illegible]	24.233	21.796	20.155	19.774
19-20	24.447	22.373	20.756	20.045	20.073
20-21	22.782	21.245	20.351	20.109	20.184
21-22	[illegible]	20.662	21.232	20.178	20.242
22-23	[illegible]	20.424	20.216	20.218	20.260
23-24	[illegible]	20.256	20.041	19.597	18.610
0- 1	[illegible]	19.940	19.470	18.747	17.947
1- 2	[illegible]	19.423	18.821	18.164	17.680
2- 3	19.427	18.376	18.303	17.933	17.573
3- 4	[illegible]	18.405	17.957	17.661	17.530
4- 5	18.483	18.059	17.747	17.576	17.512
5- 6	[illegible]	17.866	17.649	17.541	17.506

MARCH

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	-1.18	0.0	0.0	7295.7	0.0	7340.3	0.0	0.0	44.9
1- 2	-1.04	0.0	0.0	7244.6	0.0	6884.7	0.0	359.9	33.4
2- 3	-0.64	0.0	0.0	7094.3	0.0	5036.5	0.0	2057.8	22.6
3- 4	0.01	0.0	0.0	6853.4	0.0	3506.7	0.0	3346.8	14.7
4- 5	0.85	0.0	0.0	6536.1	0.0	2326.3	0.0	4209.8	9.2
5- 6	1.86	0.0	0.0	6160.7	0.0	1476.3	0.0	4684.4	5.6
6- 7	2.96	4415.6	0.0	6788.8	0.0	-25.5	0.0	6814.2	-25.5
7- 8	4.09	13026.8	3160.1	6364.8	3160.1	-25.5	0.0	3230.2	-25.5
8- 9	5.19	20747.3	9095.1	5953.2	5978.6	-24.5	3116.5	0.0	-25.5
9-10	6.20	27051.1	13750.3	5577.7	5598.3	-16.7	8152.0	0.0	-20.5
10-11	7.04	31508.6	16732.9	5260.4	5268.2	-1.4	11464.7	0.0	-7.8
11-12	7.69	33815.9	18094.6	5019.6	5009.4	17.8	13085.2	0.0	10.2
12-13	8.09	33815.9	17842.2	4869.2	4838.6	38.3	13003.6	0.0	30.6
13-14	8.23	31508.6	16120.4	4818.1	4767.2	57.5	11353.2	0.0	50.9
14-15	8.09	27051.1	13047.9	4869.2	4800.6	72.9	8247.3	0.0	68.6
15-16	7.69	20747.3	8786.2	5019.6	4938.2	82.7	3848.0	0.0	81.4
16-17	7.04	13026.7	3697.8	5260.4	3697.8	87.2	0.0	1475.3	87.3
17-18	6.20	4415.6	0.0	5577.8	0.0	5586.9	0.0	0.0	87.1
18-19	5.19	0.0	0.0	5953.2	0.0	5993.6	0.0	0.0	78.4
19-20	4.09	0.0	0.0	6364.8	0.0	6371.8	0.0	0.0	69.0
20-21	2.96	0.0	0.0	6788.8	0.0	6795.5	0.0	0.0	59.0
21-22	1.86	0.0	0.0	7200.4	0.0	7246.9	0.0	0.0	48.4
22-23	0.85	0.0	0.0	6536.1	0.0	6581.5	0.0	0.0	65.9
23-24	0.01	0.0	0.0	6853.4	0.0	6860.8	0.0	0.0	55.6
MONTHLY TOTALS		8095036.0	3730236.0	4534059.0	1489774.0	2239952.0	2240462.0	811792.1	25345.8

QXCSMT= 7449.6   QUQRM = 0.82107   QUQI = 0.46081   QAXQRM= 0.17904   QSLRQR= 0.82096

MARCH

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	17.848	17.935	17.658	17.540	17.596
7- 8	17.851	17.939	17.562	17.544	17.519
8- 9	18.551	17.942	17.666	17.549	17.514
9-10	21.232	18.339	17.758	17.598	17.533
10-11	24.71[illegible]	20.015	18.366	17.790	17.600
11-12	27.495	22.790	19.827	18.404	17.928
12-13	30.119	25.812	22.979	19.679	19.427
13-14	31.739	28.398	24.619	21.537	19.526
14-15	32.534	30.227	26.936	23.641	21.045
15-16	32.414	31.213	28.568	25.557	22.696
16-17	31.962	31.445	29.605	26.927	23.935
17-18	31.584	31.428	29.530	26.817	23.929
18-19	31.377	30.575	29.539	25.715	22.794
19-20	31.165	29.737	27.372	24.566	21.947
20-21	30.290	28.604	26.107	23.468	21.331
21-22	29.272	27.256	24.776	22.475	20.895
22-23	27.272	25.689	23.429	21.630	20.598
23-24	25.767	24.605	22.575	20.936	19.377
0- 1	25.493	23.448	21.603	20.008	18.536
1- 2	23.221	22.106	20.445	19.039	17.965
2- 3	22.361	20.705	19.325	18.296	17.695
3- 4	20.956	19.596	18.556	17.891	17.579
4- 5	18.354	18.797	18.081	17.687	17.532
5- 6	17.925	18.266	17.807	17.587	17.513

APRIL

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	4.25	0.0	0.0	5267.7	0.0	5284.8	0.0	0.0	140.6
1- 2	4.37	0.0	0.0	5219.3	0.0	5247.3	0.0	0.0	132.3
2- 3	4.76	0.0	0.0	5076.9	0.0	5097.6	0.0	0.0	124.1
3- 4	5.37	0.0	0.0	4848.7	0.0	4874.2	0.0	0.0	116.1
4- 5	6.17	0.0	0.0	4548.1	0.0	4557.7	0.0	0.0	108.5
5- 6	7.12	0.0	0.0	4192.4	0.0	4216.2	0.0	0.0	101.4
6- 7	8.16	4314.2	0.0	4842.2	0.0	4855.0	0.0	0.0	62.8
7- 8	9.24	12131.1	3237.6	4440.5	3237.6	55.2	0.0	1147.6	55.3
8- 9	10.28	19139.6	8032.5	4050.5	3995.4	56.8	4037.1	0.0	55.2
9-10	11.23	24862.0	11664.0	3694.9	3633.5	66.0	8030.6	0.0	61.4
10-11	12.03	28908.4	13975.0	3394.2	3320.4	80.6	10654.6	0.0	73.9
11-12	12.64	31002.8	15085.5	3166.1	3075.7	98.3	12009.8	0.0	90.4
12-13	13.03	31002.9	14915.4	3023.6	2914.6	116.9	12000.7	0.0	109.0
13-14	13.15	28908.4	13420.9	2975.2	2847.6	134.5	10573.3	0.0	127.6
14-15	13.03	24862.0	10609.3	3023.6	2879.7	148.7	7729.6	0.0	144.0
15-16	12.64	19139.6	6765.5	3166.1	3010.3	157.7	3755.2	0.0	155.8
16-17	12.03	12131.1	3390.9	3394.2	3232.8	161.4	158.1	0.1	161.4
17-18	11.23	4314.2	0.0	3694.9	0.0	3713.4	0.0	0.0	161.4
18-19	10.28	0.0	0.0	4050.5	0.0	4065.0	0.0	0.0	155.6
19-20	9.24	0.0	0.0	4440.5	0.0	4464.1	0.0	0.0	149.3
20-21	8.16	0.0	0.0	4842.2	0.0	4848.2	0.0	0.0	142.3
21-22	7.12	0.0	0.0	5232.1	0.0	5236.0	0.0	0.0	134.7
22-23	6.17	0.0	0.0	4548.1	0.0	4568.7	0.0	0.0	155.3
23-24	5.37	0.0	0.0	4848.7	0.0	4876.6	0.0	0.0	148.2
MONTHLY TOTALS		7221476.0	3066602.0	2999437.0	966589.4	2000228.0	2100014.0	41059.8	80507.9

@
QXCSMT= 8437.7 QUQRM = 1.0196 QUQI = 0.42465 QAXQRM= 1.36892E-02 QSLRQR= 0.98631

APRIL

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	33.673	30.472	25.521	22.272	18.934
7- 8	32.531	29.327	25.351	21.490	19.268
8- 9	32.511	29.313	25.344	21.468	19.269
9-10	30.145	29.931	27.013	23.298	20.482
10-11	30.436	30.133	28.453	25.476	22.421
11-12	32.606	30.964	29.502	27.293	24.522
12-13	35.219	32.672	30.740	28.795	26.424
13-14	37.333	34.707	32.360	30.285	28.113
14-15	37.436	36.450	34.115	31.885	29.714
15-16	37.582	37.493	35.606	33.439	31.247
16-17	37.641	37.716	36.514	34.639	32.525
17-18	37.163	37.654	36.627	34.944	32.767
18-19	37.234	37.470	36.318	34.369	30.866
19-20	37.240	37.244	35.933	33.636	29.153
20-21	37.215	36.959	35.423	32.679	27.573
21-22	37.123	36.593	34.778	31.542	26.168
22-23	36.756	36.121	33.960	30.282	24.944
23-24	35.760	35.708	33.279	29.311	23.744
0- 1	35.544	35.210	32.409	28.242	22.665
1- 2	36.225	34.599	31.566	27.087	21.692
2- 3	35.841	33.917	30.594	25.973	20.904
3- 4	35.396	33.192	29.609	24.942	20.251
4- 5	34.962	32.415	28.642	24.014	19.739
5- 6	34.374	31.641	27.725	23.202	19.336

MAY

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	11.09	0.0	0.0	2707.7	0.0	2780.6	0.0	0.0	446.6
1- 2	11.21	0.0	0.0	2664.7	0.0	2699.2	0.0	0.0	442.2
2- 3	11.54	0.0	0.0	2538.1	0.0	2539.2	0.0	0.0	438.0
3- 4	12.09	0.0	0.0	2335.2	0.0	2378.9	0.0	0.0	434.0
4- 5	12.80	0.0	0.0	2068.0	0.0	2140.0	0.0	0.0	430.3
5- 6	13.65	0.0	0.0	1751.9	0.0	1821.4	0.0	0.0	426.9
6- 7	14.57	4388.7	1098.3	2445.0	1098.3	391.4	0.0	955.3	391.2
7- 8	15.53	12394.0	1697.4	2087.9	1697.4	390.0	0.0	0.5	390.5
8- 9	16.45	19571.3	1918.1	1741.3	1351.3	390.4	566.8	0.0	389.9
9-10	17.30	25431.6	3862.7	1425.2	1034.9	392.8	2827.8	0.0	390.2
10-11	18.01	29575.4	6905.6	1157.9	763.9	398.7	6141.7	0.0	394.0
11-12	18.56	31720.4	8904.5	955.1	552.1	409.5	8352.4	0.0	403.0
12-13	18.89	31720.4	9261.4	828.5	413.1	421.7	8848.3	0.0	415.4
13-14	19.01	29575.4	7827.6	785.5	356.9	433.8	7470.8	0.0	428.6
14-15	18.89	25431.5	1778.5	828.5	388.9	441.0	1389.6	0.0	439.6
15-16	18.56	19571.3	638.9	955.1	514.0	441.0	124.9	0.1	441.1
16-17	18.01	12393.9	717.3	1157.9	717.3	440.3	0.0	0.3	440.6
17-18	17.30	4388.7	985.2	1425.2	985.2	439.7	0.0	0.2	439.9
18-19	16.45	0.0	0.0	1741.3	0.0	1797.8	0.0	0.0	439.2
19-20	15.53	0.0	0.0	2087.9	0.0	2097.5	0.0	0.0	436.4
20-21	14.57	0.0	0.0	2444.9	0.0	2470.8	0.0	0.0	433.1
21-22	13.65	0.0	0.0	2791.6	0.0	2844.4	0.0	0.0	429.3
22-23	12.80	0.0	0.0	2068.0	0.0	2147.2	0.0	0.0	453.7
23-24	12.09	0.0	0.0	2335.2	0.0	2384.4	0.0	0.0	450.3
MONTHLY TOTALS		7631031.0	1598109.0	1343150.0	315527.4	1014201.3	1282581.0	30641.9	297978.8

@
QXCSMT= 17221. QUQRM = 1.1770 QUQI = 0.20942 QAXQRM= 2.28135E-02 QSLRQR= 0.97719

MAY

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	53.155	62.979	61.591	57.453	44.513
7- 8	53.118	62.912	61.436	57.395	44.475
8- 9	53.052	62.345	61.372	57.337	44.437
9-10	55.330	62.467	61.553	59.131	47.115
10-11	56.724	60.213	61.370	59.763	52.940
11-12	[illegible]	58.990	60.110	60.223	57.062
12-13	52.557	60.289	59.763	59.925	58.720
13-14	54.346	62.476	60.775	60.083	59.430
14-15	55.309	64.092	62.328	60.978	60.051
15-16	55.147	64.307	62.700	61.275	60.243
16-17	[illegible]	64.310	62.866	61.429	60.342
17-18	64.418	64.241	62.799	61.365	60.299
18-19	64.349	64.172	62.733	61.301	60.217
19-20	64.341	64.125	62.697	61.239	59.926
20-21	64.322	64.072	62.632	61.127	57.679
21-22	64.314	64.009	62.562	60.941	56.152
22-23	64.298	63.935	62.475	60.664	54.468
23-24	64.273	63.852	62.407	60.426	53.227
0- 1	64.259	63.822	62.323	60.122	51.898
1- 2	64.235	63.751	62.213	59.720	50.412
2- 3	64.209	63.680	62.093	59.287	49.023
3- 4	64.183	63.611	61.967	58.845	47.779
4- 5	64.157	63.543	61.837	58.403	46.653
5- 6	64.133	63.481	61.710	57.935	45.675

JUNE

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	16.09	0.0	0.0	837.7	0.0	1291.1	0.0	837.7	1291.3
1- 2	16.21	0.0	0.0	794.7	0.0	1284.4	0.0	794.7	1284.5
2- 3	16.54	0.0	0.0	668.1	0.0	1272.8	0.0	668.1	1272.8
3- 4	17.09	0.0	0.0	465.2	0.0	1256.7	0.0	465.2	1256.6
4- 5	17.80	0.0	0.0	198.0	0.0	1236.4	0.0	198.0	1236.7
5- 6	18.65	0.0	0.0	-118.1	0.0	1213.9	0.0	-118.1	1214.0
6- 7	19.57	4194.0	0.0	574.9	0.0	1181.1	0.0	574.9	1181.1
7- 8	20.53	12630.2	0.0	217.9	0.0	1156.4	0.0	217.9	1156.2
8- 9	21.45	20193.9	0.0	-128.7	0.0	1131.4	0.0	-128.7	1131.9
9-10	22.30	26369.6	2763.1	0.0	0.0	1112.6	2763.1	0.0	1109.6
10-11	23.01	30736.6	5869.2	-712.1	0.0	1107.5	5869.2	-712.1	1099.3
11-12	23.56	32997.0	7427.5	-914.9	0.0	1113.9	7427.5	-914.9	1103.1
12-13	23.89	32997.0	7340.9	-1041.5	0.0	1127.3	7340.9	-1041.5	1116.6
13-14	24.01	30736.6	5547.3	-1084.5	0.0	1142.4	5547.3	-1084.5	1134.7
14-15	23.89	26369.6	2309.4	-1041.5	0.0	1154.1	2309.4	-1041.5	1151.9
15-16	23.56	20193.9	0.0	-914.9	0.0	1162.8	0.0	-914.9	1163.1
16-17	23.01	12630.2	0.0	-712.1	0.0	1171.1	0.0	-712.1	1171.2
17-18	22.30	4194.0	0.0	0.0	0.0	1183.1	0.0	0.0	1183.1
18-19	21.45	0.0	0.0	-128.7	0.0	1197.8	0.0	-128.7	1197.8
19-20	20.53	0.0	0.0	217.9	0.0	1214.4	0.0	217.9	1214.2
20-21	19.57	0.0	0.0	574.9	0.0	1231.4	0.0	574.9	1231.2
21-22	18.65	0.0	0.0	921.6	0.0	1246.9	0.0	921.6	1247.5
22-23	17.80	0.0	0.0	198.0	0.0	1261.9	0.0	198.0	1262.0
23-24	17.09	0.0	0.0	465.2	0.0	1273.9	0.0	465.2	1273.6
MONTHLY TOTALS		7627270.0	996172.6	-19887.7	0.0	841692.2	996172.6	-19887.7	840340.1

a

QUQI = 0.13061

JUNE

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNINGS OF HOUR INDICATED				
6- 7	73.740	74.057	73.673	72.783	71.725
7- 8	73.566	73.877	73.493	72.606	71.552
8- 9	73.341	73.700	73.317	72.434	71.393
9-10	73.219	73.526	73.145	72.265	71.217
10-11	73.441	73.339	73.176	72.701	71.965
11-12	75.465	74.090	73.377	72.920	72.350
12-13	77.242	75.496	74.169	73.332	72.789
13-14	78.178	76.792	75.318	74.116	73.230
14-15	78.055	77.455	76.350	75.099	73.991
15-16	76.963	77.251	76.863	75.945	74.852
16-17	76.732	77.073	76.696	75.772	74.682
17-18	76.551	76.893	76.503	75.597	74.511
18-19	76.373	76.712	76.325	75.420	74.327
19-20	76.192	76.523	76.146	75.241	74.162
20-21	76.067	76.343	75.962	75.059	73.984
21-22	75.820	76.155	75.775	74.875	73.804
22-23	75.639	75.964	75.585	74.689	73.621
23-24	75.434	75.771	75.393	74.500	73.435
0- 1	75.245	75.577	75.200	74.310	73.249
1- 2	75.042	75.379	75.004	74.117	73.059
2- 3	74.854	75.183	74.809	73.924	72.870
3- 4	74.660	74.989	74.616	73.734	72.684
4- 5	74.463	74.796	74.425	73.546	72.499
5- 6	74.231	74.607	74.237	73.361	72.318

JULY

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	19.00	0.0	0.0	-248.9	0.0	1307.8	0.0	-248.9	1308.2
1- 2	19.10	0.0	0.0	-286.2	0.0	1301.7	0.0	-286.2	1301.6
2- 3	19.39	0.0	0.0	-395.8	0.0	1291.1	0.0	-395.8	1290.9
3- 4	19.86	0.0	0.0	-571.5	0.0	1275.8	0.0	-571.5	1276.2
4- 5	20.48	0.0	0.0	-802.9	0.0	1258.3	0.0	-802.9	1258.4
5- 6	21.21	0.0	0.0	0.0	0.0	1238.1	0.0	0.0	1238.1
6- 7	22.01	4292.6	0.0	0.0	0.0	1214.4	0.0	0.0	1214.4
7- 8	22.84	12850.7	0.0	-646.4	0.0	1192.2	0.0	-646.4	1192.2
8- 9	23.64	20523.6	0.0	-946.6	0.0	1170.3	0.0	-946.6	1170.5
9-10	24.37	26788.6	2571.7	-1220.4	0.0	1153.1	2571.7	-1220.4	1150.5
10-11	24.99	31218.6	5670.2	-1451.9	0.0	1149.3	5670.2	-1451.9	1141.6
11-12	25.46	33511.7	7218.3	-1627.5	0.0	1156.6	7218.3	-1627.5	1146.2
12-13	25.75	33511.8	7128.7	-1737.2	0.0	1170.1	7128.7	-1737.2	1159.9
13-14	25.85	31218.6	5340.8	-1774.4	0.0	1184.7	5340.8	-1774.4	1177.5
14-15	25.75	26788.6	2113.6	-1737.2	0.0	1195.3	2113.6	-1737.2	1193.4
15-16	25.46	20523.6	0.0	-1627.5	0.0	1202.8	0.0	-1627.5	1202.9
16-17	24.99	12850.6	0.0	-1451.9	0.0	1209.2	0.0	-1451.9	1209.3
17-18	24.37	4292.5	0.0	-1220.4	0.0	1219.2	0.0	-1220.4	1218.9
18-19	23.64	0.0	0.0	-946.6	0.0	1230.6	0.0	-946.6	1231.0
19-20	22.84	0.0	0.0	-646.4	0.0	1244.7	0.0	-646.4	1244.6
20-21	22.01	0.0	0.0	0.0	0.0	1258.3	0.0	0.0	1258.7
21-22	21.21	0.0	0.0	-37.0	0.0	1272.2	0.0	-37.0	1272.2
22-23	20.48	0.0	0.0	-802.9	0.0	1284.2	0.0	-802.9	1284.1
23-24	19.86	0.0	0.0	-571.5	0.0	1293.6	0.0	-571.5	1293.5
MONTHLY TOTALS		8009513.0	945863.6	-643288.9	0.0	909065.9	945863.6	-643288.9	907834.9

@
QUQI = 0.11809

JULY

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	[illegible]	77.961	77.629	76.775	75.763
7- 8	[illegible]	77.776	77.435	76.594	75.585
8- 9	[illegible]	77.593	77.254	76.415	75.410
9-10	[illegible]	77.414	77.076	76.240	75.238
10-11	77.332	77.196	77.063	76.632	75.679
11-12	[illegible]	77.719	77.234	76.810	76.279
12-13	[illegible]	79.289	77.992	77.197	76.599
13-14	[illegible]	80.544	79.105	77.336	77.082
14-15	81.726	81.169	80.034	78.882	77.907
15-16	[illegible]	80.229	80.574	79.690	78.631
16-17	[illegible]	80.745	80.391	79.511	78.454
17-18	[illegible]	80.560	80.227	79.330	78.277
18-19	[illegible]	80.374	80.022	79.147	78.098
19-20	[illegible]	80.185	79.835	78.963	77.916
20-21	79.632	79.995	79.646	78.777	77.735
21-22	[illegible]	79.803	79.455	78.589	77.550
22-23	[illegible]	79.609	79.262	78.399	77.363
23-24	[illegible]	79.412	79.067	78.206	77.175
0- 1	[illegible]	79.215	78.870	78.013	76.984
1- 2	[illegible]	79.015	78.672	77.817	76.792
2- 3	[illegible]	78.816	78.474	77.622	76.601
3- 4	[illegible]	78.619	78.276	77.429	76.411
4- 5	78.079	78.424	78.084	77.238	76.223
5- 6	[illegible]	78.232	77.893	77.050	76.038

AUGUST

HOUR	AMBIENT TEMP (C)	HOURLY INCIDENT HEAT (W-HR)	HOURLY USEFUL HEAT (W-HR)	HOURLY ROOM HEAT NEEDS (W-HR)	HOURLY COLLECTED HEAT TO ROOM (W-HR)	HOURLY STORAGE HEAT TO SURR (W-HR)	HOURLY COLLECTED HEAT TO STORAGE (W-HR)	HOURLY AUXILIARY HEAT TO ROOM (W-HR)	HOURLY STORAGE LOSS TO SURR (W-HR)
0- 1	18.54	0.0	0.0	-78.1	0.0	1297.5	0.0	-78.1	1297.5
1- 2	18.63	0.0	0.0	-111.9	0.0	1291.1	0.0	-111.9	1291.3
2- 3	18.90	0.0	0.0	-211.3	0.0	1281.1	0.0	-211.3	1281.1
3- 4	19.32	0.0	0.0	-370.7	0.0	1267.5	0.0	-370.7	1267.5
4- 5	19.88	0.0	0.0	-580.7	0.0	1250.8	0.0	-580.7	1250.9
5- 6	20.55	0.0	0.0	-829.1	0.0	1232.2	0.0	-829.1	1232.1
6- 7	21.27	4442.6	0.0	-61.7	0.0	1212.5	0.0	-61.7	1212.5
7- 8	22.03	12662.9	0.0	0.0	0.0	1191.7	0.0	0.0	1191.9
8- 9	22.75	20033.1	0.0	0.0	0.0	1171.9	0.0	0.0	1171.9
9-10	23.42	26050.9	0.0	-863.0	0.0	1156.2	0.0	-863.0	1153.4
10-11	23.98	30306.1	2670.9	-1072.9	0.0	1153.5	2670.9	-1072.9	1146.1
11-12	24.40	32508.7	5499.4	-1232.3	0.0	1160.9	5499.4	-1232.3	1151.1
12-13	24.67	32508.7	6901.7	-1331.8	0.0	1174.0	6901.7	-1331.8	1164.3
13-14	24.76	30306.1	6812.6	-1365.6	0.0	1189.0	6812.6	-1365.6	1181.0
14-15	24.67	26050.9	5174.0	-1331.8	0.0	1198.2	5174.0	-1331.8	1196.2
15-16	24.40	20033.1	2211.6	-1232.3	0.0	1205.6	2211.6	-1232.3	1205.4
16-17	23.98	12662.9	0.0	-1072.9	0.0	1210.6	0.0	-1072.9	1210.8
17-18	23.42	4442.5	0.0	-863.0	0.0	1219.2	0.0	-863.0	1219.2
18-19	22.75	0.0	0.0	0.0	0.0	1230.0	0.0	0.0	1229.8
19-20	22.03	0.0	0.0	0.0	0.0	1241.4	0.0	0.0	1241.7
20-21	21.27	0.0	0.0	-61.7	0.0	1254.2	0.0	-61.7	1254.1
21-22	20.55	0.0	0.0	210.7	0.0	1266.1	0.0	210.7	1266.0
22-23	19.88	0.0	0.0	-580.7	0.0	1276.1	0.0	-580.7	1276.4
23-24	19.32	0.0	0.0	-370.7	0.0	1284.7	0.0	-370.7	1284.6
MONTHLY TOTALS		7812256.0	903664.7	-415753.1	0.0	913031.4	903664.7	-415753.1	911867.1

@ QUGI = 0.11567

@ NRSEGS= 7

@ TOTSEG= 7.0000 NRSEGS= 7

AUGUST

HOUR	STORAGE SEGMENT TEMPERATURE AT BEGINNING OF HOUR INDICATED				
6- 7	[illegible]	77.109	76.757	75.945	74.978
7- 8	76.641	76.923	76.575	75.764	74.800
8- 9	[illegible]	76.741	76.392	75.585	74.625
9-10	76.292	76.552	76.214	75.410	74.453
10-11	[illegible]	76.397	76.231	75.790	75.061
11-12	[illegible]	77.099	76.416	75.979	75.450
12-13	80.004	78.394	77.145	76.355	75.769
13-14	[illegible]	79.558	78.194	77.073	76.242
14-15	80.717	80.155	79.120	77.968	76.935
15-16	79.664	79.969	79.590	78.735	77.718
16-17	[illegible]	79.776	79.407	78.555	77.541
17-18	[illegible]	79.590	79.223	78.374	77.363
18-19	79.111	79.404	79.038	78.192	77.184
19-20	78.924	79.216	78.852	78.008	77.004
20-21	[illegible]	79.027	78.663	77.822	76.822
21-22	78.545	78.835	78.473	77.635	76.637
22-23	[illegible]	78.642	78.281	77.445	76.451
23-24	78.157	78.447	78.087	77.255	76.264
0- 1	[illegible]	78.251	77.892	77.062	76.075
1- 2	77.766	78.053	77.695	76.868	75.884
2- 3	77.570	77.855	77.499	76.675	75.694
3- 4	77.375	77.660	77.305	76.483	75.506
4- 5	[illegible]	77.466	77.112	76.294	75.319
5- 6	76.993	77.275	76.923	76.107	75.135

COMPUTER NOMENCLATURE
FOR FIGURE A.2

AREAC	surface area of collector
DEGDAY	heat load of dwelling; (W-HR/°C-HR)
ΔT	difference in temperature between storage bed surroundings and average temperature in bed
ΔT_{stor}	change in temperature of storage due to heating bed with the collector
ΔQPB	heat transferred from storage while storage is idle (convective losses)
ΔQRB	heat transeferred to storage from collector
DLTIME	time, in seconds, remaining in any given hour for performing any of the several modes of heat transfer possible in this simulation
DLTIMH	one hour in seconds
IFLAG	when equal to 1, indicates the collector is presently heating storage after having heated the dwelling; used as an internal logic signal only
QADINT	heat transferred in an interval (either 60 sec or 5 sec) when storage used to heat dwelling
QADTOT	heat transferred while heating room from storage
QAUX	auxiliary heat required by dwelling
QAXQRM	monthly ratio of auxiliary heat supplied to room needs
QI	solar radiation incident upon collector
QLOSSH	Total amount of heat lost from storage to room while storage being heated by collector (QLOSS refers to the amount lost in either 60 sec or 5 sec)

QRATIO	ratio of energy supplied from storage in small interval to the room needs in that interval
QRMFMC	heat transferred to the dwelling from collector
QRMFMS	heat transferred to the dwelling from storage
QROOM	hourly room energy requirement
QROOM1	hourly room energy requirement accounting for the uncontrolled storage loss
QSLRQR	monthly ratio of solar energy supplied to room needs
QSTFMC	heat transferred to storage from collector
QSUBLS	uncontrolled convective losses from storage
QU	hourly thermal energy extracted from the collector by the system = QRMFMC + QSTFMC
QUQI	ratio of QU to QI
QUQRM	ratio of QU to QROOM
QXCES	the hourly amount of energy supplied to the residence for which there is no need (convective losses or "overshoot" from storage)
QXCSMT	monthly total of QXCES
SI	flux of solar radiation incident upon the collector surface area
SURFAR	surface area of storage bed through which convective loss takes place
TAMB	ambient temperature
TAVCHK	maximum average storage temperature allowed
TREF	average value of allowable room temperature range
TSAVG	average instantaneous temperature in storage bed

LISTING OF
COMPUTER
SIMULATION

TABLE A.3

```
USER=RAMSAY   662 21451     JOINT COMPUTER FACILITY, MIT

      REAL KT, KTKD, LENGTH, KINS,  N, KAIR, MU, MDOT
      DIMENSION   KT(12), H(12), XDAYS(12), TSUBBS(33), AVDAT(12),
     1            TSUBFS(33), TIME(24), TSBBSH(33), XTAMB(24),
     2            XQI(24), XQU(24), XQROOM(24), XQRMFC(24), XQSBLS(24),
     3            XQRMFS(24), XQSTFC(24), YQAUX(24), AVNIT(12),
     4             YQAUX(24), YQXCES(24), YQI(24), YQU(24), YQROOM(24),
     5            YQSBLS(24), YQRMFC(24), YQRMFS(24), YQSTFC(24),
     6            XQXCES(24)
      READ (8,10) TIME, H, KT, XDAYS, AVDAT, AVNIT
      ALF60D=0.8346
      BETA=50.0
      CVRNBR=2.
      DEGDAY=374.0
      DLTIMH=3600.0
      DSCHGT=60.0
      DUST=0.02
      EMISGL=0.88
      EMISPL=0.95
      EPS1=EMISPL
      EPS2=EMISPL
      GAMMA=0.0
      KAIR=0.029
      KINS=0.043
      MDOT=1.2
      MU=1.912E-5
      PBLDIA=0.0508
      PHI=40.77
      PI=3.141593
      PLTSPC=0.01
      DO 500 KK=1,3
      IF (KK .EQ. 1)  AREAXS=6.0
      IF (KK .EQ. 1)  LENGTH=2.0
      IF (KK .EQ. 2)  AREAXS=6.8
```

```
      IF (KK .EQ. 2)  LENGTH=2.5
      IF (KK .EQ. 3)  AREAXS=7.5
      IF (KK .EQ. 3)  LENGTH=3.2
      PLLONG=5.0
      PLWDTH=12.0
      RFRNDX=1.526
      RHOGR=0.2
      RHOPBL=2400.0
      SHADE=0.03
      SIGMA=5.6697E-8
      SPHTFL=1.012
      SPHTPB=0.837
      TASHRA=62.78
      TASHRM=85.0
      THKINS=0.076
      THTA60=60.*PI/180.
      TRDWH=21.11
      TRDWL=19.44
      TRNWH=18.33
      TRNWL=16.67
      TRDSH=22.78
      TRDSL=21.11
      TRNSH=22.78
      TRNSL=18.33
      VOIDR=0.3
      VWIND=5.0
      AREAC=PLWDTH*PLLONG
      BTARDN=BETA*PI/180.
      FLOARA=PLTSPC*PLWDTH
      G=MDOT/AREAC
      GMMRDN=GAMMA*PI/180.
      H1=(0.0158*(MDOT*PLTSPC*2.0/(FLOARA*MU))**0.8*KAIR)/(PLTSPC*2.0)
      H2=H1
```

```
      HR=4.0*SIGMA*(340.0**3)/(1./EPS1+1./EPS2-1.0)
      HV=650.0*(((MDOT/AREAXS)/(PBLDIA))**0.7)
      SEGDET=0.0
 17   SEGDET=SEGDET+1.0
      HALMCS=(HV*AREAXS*LENGTH*1.E-3)/(MDOT*SPHTFL*SEGDET)
      DELTAU=((RHOPBL*AREAXS*LENGTH/SEGDET)*(1.0-VOIDR)*SPHTPB)/((MDOT*
     1        SPHTFL)*(1.0-EXP(-(HALMCS))))
      IF (DELTAU .GT. 3600.0)  GO TO 17
      TOTSEG=SEGDET-1.0
      HALMCN=(HV*AREAXS*LENGTH*1.E-3)/(MDOT*SPHTFL*TOTSEG)
      NRSEGS=IFIX(SEGDET-1.0)
      PUT NRSEGS
      DO 6 I1=1,NRSEGS
      TSUBBS(I1)=62.78
 6    CONTINUE
      NRSEG1=NRSEGS+1
      TSUBFS(1)=20.27
      TSUBFS(NRSEG1)=62.78
      PUT TOTSEG, NRSEGS
      HWIND=5.7+3.8*VWIND
      PHIRDN=PHI*PI/180.
      RHOLAN=RHOPBL*AREAXS*LENGTH/TOTSEG
      RSUBPF=1.0/(AREAC*H1)
      SURFAR=(LENGTH*PI*(2.0*SQRT(AREAXS/PI))+2.0*AREAXS)/TOTSEG
      THTA26=ASIN(SIN(THTA60)/RFRNDX)
      RHO60D=.5*(((SIN(THTA26-THTA60))**2/(SIN(THTA26+THTA60))**2)+((
     1        TAN(THTA26-THTA60))**2/(TAN(THTA26+THTA60))**2))
      TAU60D=(1.-RHO60D)/(1.+(2.*CVRNBR-1.)*RHO60D)
      TAUALD=(TAU60D*ALF60D)/(1.-(1.-ALF60D)*RHO60D)
C
      IFLAG1=1
C
C
```

```
      DO 1 II=1,12
      DO 84 KI=1,24
      YQI(KI)=0.0
      YQU(KI)=0.0
      YQROOM(KI)=0.0
      YQSBLS(KI)=0.0
      YQRMFC(KI)=0.0
      YQRMFS(KI)=0.0
      YQSTFC(KI)=0.0
      YQAUX(KI)=0.0
      YQXCES(KI)=0.0
 84   CONTINUE
      IIFLAG=0
 19   IIFLAG=IIFLAG+1
      I=II+8
      IF (II .GE. 5)  I=II-4
      IF (IIFLAG .LE. 8)  GO TO 601
      GO TO (64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75), I
 64             WRITE (5,1001)
                GO TO 76
 65             WRITE (5,1002)
                GO TO 76
 66             WRITE (5,1003)
                GO TO 76
 67             WRITE (5,1004)
                GO TO 76
 68             WRITE (5,1005)
                GO TO 76
 69             WRITE (5,1006)
                GO TO 76
 70             WRITE (5,1007)
                GO TO 76
 71             WRITE (5,1008)
```

```
                  GO TO 76
 72               WRITE (5,1009)
                  GO TO 76
 73               WRITE (5,1010)
                  GO TO 76
 74               WRITE (5,1011)
                  GO TO 76
 75               WRITE (5,1012)
 76     WRITE (5,1027)
 601    KTKD=.795-.84*KT(I)
        N=INT(-16.3+30.5*FLOAT(I)+0.5)
        DELTA=23.45*SIN((360.*(284.+N)/365.)*PI/180.)
        DLTRDN=DELTA*PI/180.
        COSWS=-(TAN(PHIRDN)*TAN(DLTRDN))
        TAVCHK=TASHRA
        IF (II .GE. 10)  TAVCHK=TASHRM
C
        DO 2 JJ=1,24
        J=JJ+6
        IF (JJ .GE. 19)  J=JJ-18
C
        IHOURB=J-1
        IHOURS=J
        TAMB=(AVDAT(I)+AVNIT(I))/2.0+(((AVDAT(I)-AVNIT(I))/(2.0*0.7071))*
       1      SIN((PI/13.0)*TIME(J)-7.0*PI/13.0))
        IF (IFLAG1 .EQ. 1)  TPLATC=TAMB+10.0
        IFLAG1=0
        TAMBK=TAMB+273.15
        QXCES=0.0
        QRMFMS=0.0
        IFLAG=0
        DLTIME=DLTIMB
        TREF=TRDWH
```

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```
      TRMIN=TRDWL
      IF (JJ .GE. 17)  TREF=TRNWH
      IF (JJ .GE. 17)  TRMIN=TRNWL
      IF (II .LE.9)  GO TO 60
           TREF=TRDSL
           TRMIN=TRDSH
      IF (JJ .GE. 17)  TREF=TRNSL
      IF (JJ .GE. 17)  TRMIN=TRNSH
 60   TSURR=(TREF+TRMIN)/2.0
      TSURS=TSURR
      IF (II .GE. 10)  TSURS=TAMB
 61   QROOM=DEGDAY*(TREF-TAMB)
      IF (TAMB .GE. TRDSH)  GO TO 608
      IF (TAMB .GE. TSURR)  QROOM=0.0
 608  USUBLS=0.283
      IF  (II .GE. 10)  USUBLS=0.6
      QSUBLS=0.0
 609  DO 63 I5=1,NRSEGS
      QSUBLS=USUBLS*SURFAR*(TSUBBS(I5)-TSURS)+QSUBLS
 63   CONTINUE
 62   QROOM1=QROOM-QSUBLS
      W=(12.-TIME(J))*15.0*PI/180.0
      COSW=COS(W)
      COSTHT=COS(DLTRDN)*COS(W)*(COS(GMMRDN)*SIN(BTARDN)*SIN(PHIRDN)+
     1       COS(PHIRDN)*COS(BTARDN))+SIN(GMMRDN)*SIN(BTARDN)*COS(DLTR
     2       DN)*SIN(W)+SIN(DLTRDN)*(SIN(PHIRDN)*COS(BTARDN)-COS(GMMRDN
     3       )*COS(PHIRDN)*SIN(BTARDN))
      SNALFA=SIN(DLTRDN)*SIN(PHIRDN)+COS(DLTRDN)*COS(PHIRDN)*COS(W)
      RSUBB=COSTHT/SNALFA
      RSUBD=PI/24.*(COS(W)-COSWS)/(SIN(ACOS(COSWS))-ACOS(COSWS)*COSWS)
      SI=RSUBD*H(I)*1.0E4*((RSUBB*(1.0-KTKD))+(0.5*(1.0+COS(BTARDN))*
     1  KTKD)+(0.5*(1.0-COS(BTARDN))*RHOGR))/3.6
      IF (SI .GT. 0.0)  GO TO 18
```

```
            SI=0.0
            QI=0.0
            QU=0.0
            QSTFMC=0.0
            QRMFMC=0.0
      IF  (II .GE. 10)  GO TO 40
      IF (QROOM1 .GT. 0.0)  GO TO 121
            QRMFMS=0.0
            GO TO 40
 18   QI=SI*AREAC
      THETAT=ACOS(COSTHT)
      THTA2T=ASIN(SIN(THETAT)/RFRNDX)
      RHOTHT=.5*(((SIN(THTA2T-THETAT))**2/(SIN(THTA2T+THETAT))**2)+((
     1       TAN(THTA2T-THETAT))**2/(TAN(THTA2T+THETAT))**2))
      ALFTHT=1.0-20.03/((100.03-THETAT)**1.3)
      TAUTHT=(1.-RHOTHT)/(1.+(2.*CVRNBR-1.)*RHOTHT)
      TAUALB=(TAUTHT*ALFTHT)/(1.-(1.-ALFTHT)*RHO60D)
      S=(TAUALB*RSUBD*H(I)*1.0E4*RSUBB*(1.0-KTKD)+TAUALD*RSUBD*H(I)
     1 *1.0E4/2.0*((1.0+COS(BTARDN))*KTKD+(1.0-COS(BTARDN))*RHOGR))*
     2 (1.0-SHADE)*(1.0-DUST)/3.6
      IF  (II .GE. 10)  GO TO 77
      IF (QROOM1 .GT. 0.0)  GO TO 824
 77   TSSUM=0.0
      DO 82 IK=1,NRSEGS
      TSSUM=TSSUM+TSUBBS(IK)
 82   CONTINUE
      TSAVG=TSSUM/TOTSEG
      IF (TSAVG .LT. TAVCHK)  GO TO 880
            QU=0.0
            QRMFMC=0.0
            QSTFMC=0.0
            QRMFMS=0.0
            IFLAG=0
```

```
            GO TO 40
 850        TSBFI=TSUBBS(NRSEGS)
            QRMFMC=0.0
            QRMFMS=0.0
            GO TO 825
 824        TSBFI=TSURR
 825   IFLAG=0
C
 111   TPLATI=TPLATC
       TPLTIK=TPLATC+273.15
       IF (QI .NE. 0.0)  GO TO 827
       TPLATI=TAMB+10.0
       TPLTIK=TPLATI+273.15
 827   SMALF=(1.0-0.04*HWIND+5.0E-4*(HWIND)**2)*(1.0+0.058*CVRNBR)
       UT45DG=(1./(CVRNBR/((344./TPLTIK)*((TPLTIK-TAMBK)/(CVRNBR+SMALF)
     1       )**.31)+1./HWIND))+((SIGMA*(TPLTIK+TAMBK)*(TPLTIK**2+TAMBK
     2        **2))/((1./(EMISPL+.0425*CVRNBR*(1.-EMISPL)))+((2.*CVRNBR
     3        +SMALF-1.)/EMISGL)-CVRNBR))
       UTBETA=UT45DG*(1.-(BETA-45.)*(.00259-.00144*EMISPL))
       USUBT=UTBETA
       USUBB=KINS/THKINS
       USUBL=USUBT+USUBB
       FPRIME=1./(1.+(USUBL/(H1+1./(1./H2+1./HR))))
       USBLJ=0.001*USUBL
       FSUBR=(G*SPHTFL/USBLJ)*(1.-EXP(-(USBLJ*FPRIME)/(G*SPHTFL)))
       QUAC=FSUBR*(S-USUBL*(TSBFI-TAMB))
       TSBFM=TSBFI+(QUAC/(USUBL*FSUBR))*(1.-FSUBR/FPRIME)
       QU=QUAC*AREAC
       TPLATC=TSBFM+QU*RSUBPF
       IF ( ABS(TPLATC-TPLATI) .GT. 1.0)  GO TO 111
       IF (IFLAG .EQ. 1)  GO TO 771
       IF  (II .GE. 10)  GO TO 55
       IF (QROOM1 .GT. 0.0)  GO TO 32
```

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 55   IF (QU .GT. 0.0)  GO TO 81
          QU=0.0
          QSTFMC=0.0
          GO TO 40
 32   IF (QU .GT. 0.0)  GO TO 411
          QU=0.0
          QSTFMC=0.0
          QRMFMC=0.0
          GO TO 121
C
 81   TSBFO=(QU*0.001)/(MDOT*SPHTFL)+TSBFI
      IF (DLTIME .GE. 5.0)  GO TO 87
          QU=QROOM1
          QSTFMC=0.0
          IFLAG=0
          GO TO 11
 87   IF (IFLAG .NE. 1)  GO TO 881
      IF (QU .GT. 0.0)  GO TO 102
          QSTFMC=0.0
          IFLAG=0
          QU=QROOM1
          GO TO 11
 881  IF (IIFLAG .LE. 8)  GO TO 102
      WRITE (5,1019)
      WRITE (5,1021) IHOURB, IHOURE
      WRITE(5,101) (TSUBBS(L3),L3=1,NRSEGS)
 102  SUMINT=0.0
      DSCHGT=60.0
      IFLAG6=0
      IFLAG7=0
      QPBZ=0.0
      QLOSSH=0.0
 113  TSUBFS(1)=TSBFO
```

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      DO 3 K=1,NRSEGS
      TSUBFS(K+1)=(TSUBFS(K)-TSUBBS(K))*EXP(-(HALMCN))+TSUBBS(K)
 3    CONTINUE
      TSSUM=0.0
      DO 79 IK=1,NRSEGS
      TSSUM=TSSUM+TSUBBS(IK)
 79   CONTINUE
      TSAVH=TSSUM/TOTSEG
      QPBA=(RHOLAN*TOTSEG*SPHTPB*(1.0-VOIDR)*TSAVH)/3.6
      IF (IFLAG7 .EQ. 1)  GO TO 103
         QPB1=QPBA
         IFLAG7=1
 103  DO 4 L=1,NRSEGS
      TSBBSH(L)=((MDOT*SPHTFL*(TSUBFS(L)-TSUBFS(L+1))-USUBLS*0.001*
     1           SURFAR*(TSUBBS(L)-TSURS))*DSCHGT)/(RHOLAN*(1.0-VOIDR)
     2           *SPHTPB)+TSUBBS(L)
 4    CONTINUE
      TSSUM=0.0
      DO 80 IK=1,NRSEGS
      TSSUM=TSSUM+TSBBSH(IK)
 80   CONTINUE
      TSAVG=TSSUM/TOTSEG
      IF ((TSAVG-TSAVH) .GE. (0.0005*DSCHGT/60.0))  GO TO 29
         DLTCHK=DLTIME-SUMINT
         GO TO 48
 29   SUMINT=SUMINT+DSCHGT
      DLTCHK=DLTIME-SUMINT
      IF (DLTCHK .GE. 0.0)  GO TO 30
         IF (IFLAG6 .EQ. 0)  GO TO 28
            DLTCHK=DLTCHK+DSCHGT
            GO TO 48
 28      DLTCHK=DLTCHK+DSCHGT
         SUMINT=SUMINT-DSCHGT
```

```
          DSCHGT=5.0
          IFLAG6=1
          GO TO 113
 30   DO 31 IK=1,NRSEGS
      TSUBBS(IK)=TSBBSH(IK)
 31   CONTINUE
      QPBZ=(RHOLAN*TOTSEG*SPHTPB*(1.0-VOIDR)*TSAVG)/3.6
      QLOSS=0.0
      DO 201  I5=1,NRSEGS
      QLOSS=USUBLS*SURFAR*(TSUBBS(I5)-TSURS)*DSCHGT/3600.0+QLOSS
 201  CONTINUE
      QLOSSH=QLOSS+QLOSSH
      IF (DLTCHK .EQ. 0.0)  GO TO 48
      IF (TSAVG .LT. TAVCHK)  GO TO 113
 48   QU=(QPBZ-QPB1)+QLOSSH
      IF ((TSAVG-TSAVH) .LT. (0.0005*DSCHGT/60.0))   QU=(QPBA-QPB1)+
     1    QLOSSH
      QRMFMS=QRMFMS+QLOSSH
      QSTFMC=QU
      IF (IFLAG .EQ. 1)  QU=QSTFMC+QROOM1
      IFLAG=0
          IF (DLTCHK .LE. 0.0)  DLTCHK=0.0
          DLTIME=DLTCHK
          DSCHGT=60.0
          GO TO 11
 50   XTAMB(J)=TAMB
      XQI(J)=QI
      XQU(J)=QU
      XQROOM(J)=QROOM
      XQSBLS(J)=QSUBLS
      XQRMFC(J)=QRMFMC
      XQRMFS(J)=QRMFMS
      XQSTFC(J)=QSTFMC
```

```
      XQAUX(J)=QAUX
      XQXCES(J)=QXCES
      YQI(J)=QI+YQI(J)
      YQU(J)=QU+YQU(J)
      YQROOM(J)=QROOM+YQROOM(J)
      YQSBLS(J)=QSUBLS+YQSBLS(J)
      YQRMFC(J)=QRMFMC+YQRMFC(J)
      YQRMFS(J)=QRMFMS+YQRMFS(J)
      YQSTFC(J)=QSTFMC+YQSTFC(J)
      YQAUX(J)=QAUX+YQAUX(J)
      YQXCES(J)=QXCES+YQXCES(J)
 2    CONTINUE
      IF (IIFLAG .LE. 8)  GO TO 19
      QIM=0.0
      QUM=0.0
      QRMM=0.0
      QSBLSM=0.0
      QRFMCM=0.0
      QRFMSM=0.0
      QSFMCM=0.0
      QAUXM=0.0
      QXCESM=0.0
      QI5=0.0
      QU5=0.0
      QRM5=0.0
      QSBLS5=0.0
      QRFMC5=0.0
      QRFMS5=0.0
      QSFMC5=0.0
      QAUX5=0.0
      QXCES5=0.0
      DO 1030 J8=1,24
      QIM=XQI(J8)+QIM
```

```
      QUM=XQU(J8)+QUM
      QRMM=XQROOM(J8)+QRMM
      QSBLSM=XQSBLS(J8)+QSBLSM
      QRFMCM=XQRMFC(J8)+QRFMCM
      QRFMSM=XQRMFS(J8)+QRFMSM
      QSFMCM=XQSTFC(J8)+QSFMCM
      QAUXM=XQAUX(J8)+QAUXM
      QXCESM=XQXCES(J8)+QXCESM
      QI5=YQI(J8)+QI5
      QU5=YQU(J8)+QU5
      QRM5=YQROOM(J8)+QRM5
      QSBLS5=YQSBLS(J8)+QSBLS5
      QRFMC5=YQRMFC(J8)+QRFMC5
      QRFMS5=YQRMFS(J8)+QRFMS5
      QSFMC5=YQSTFC(J8)+QSFMC5
      QAUX5=YQAUX(J8)+QAUX5
      QXCES5=YQXCES(J8)+QXCES5
 1030 CONTINUE
      QIMT=(XDAYS(I)-9.0)*QIM+QI5
      QUMT=(XDAYS(I)-9.0)*QUM+QU5
      QRMMT=(XDAYS(I)-9.0)*QRMM+QRM5
      QBLSMT=(XDAYS(I)-9.0)*QSBLSM+QSBLS5
      QRFCMT=(XDAYS(I)-9.0)*QRFMCM+QRFMC5
      QRFSMT=(XDAYS(I)-9.0)*QRFMSM+QRFMS5
      QSFCMT=(XDAYS(I)-9.0)*QSFMCM+QSFMC5
      QAUXMT=(XDAYS(I)-9.0)*QAUXM+QAUX5
      QXCSMT=QXCES5+(XDAYS(I)-9.0)*QXCESM
      QUQRM=(QUMT-QXCSMT)/QRMMT
      QUQI=QUMT/QIMT
      QAXQRM=QAUXMT/QRMMT
      QSLRQR=1.0-QAXQRM
      GO TO (164,165,166,167,168,169,170,171,172,173,174,175),I
 164           WRITE (5,1001)
```

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```
                  GO TO 176
 165              WRITE (5,1002)
                  GO TO 176
 165              WRITE (5,1003)
                  GO TO 176
 167              WRITE (5,1004)
                  GO TO 176
 168              WRITE (5,1005)
                  GO TO 176
 169              WRITE (5,1006)
                  GO TO 176
 170              WRITE (5,1007)
                  GO TO 176
 171              WRITE (5,1008)
                  GO TO 176
 172              WRITE (5,1009)
                  GO TO 176
 173              WRITE (5,1010)
                  GO TO 176
 174              WRITE (5,1011)
                  GO TO 176
 175              WRITE (5,1012)
 176              WRITE (5,1014)
                  WRITE (5,1015)
                  WRITE (5,1016)
                  WRITE (5,1017)
                  WRITE (5,1018)
       DO 1020 J5=1,24
       IHOURB=J5-1
       IHOURE=J5
                  WRITE (5,1019)
                  WRITE (5,1021)  IHOURB, IHOURE
       WRITE(5,1022) XTAMB(J5), XQI(J5), XQU(J5), XQROOM(J5),
```

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     1                XQRMFC(J5), XQRMFS(J5), XQSTFC(J5), XQAUX(J5),
     2                XQSBLS(J5)
 1020 CONTINUE
      WRITE (5,1023)
      WRITE (5,1024)
      WRITE (5,1025) QIMT, QUMT, QRMMT, QRFCMT, QRFSMT, QSFCMT, QAUXMT,
     1               QBLSMT
      IF (II .LE. 9) PUT QXCSMT,QUQRM, QUQI, QAXQRM, QSLRQR
      IF (II .GT. 9) PUT QUQI
 1    CONTINUE
 500  CONTINUE
      STOP
C
C
C     COLLECTOR HAS SUPPLIED THE ROOM NEEDS IN FULL WITH POTENTIALLY
C     SOME ENERGY LEFT FOR STORAGE
 771  TSSUM=0.0
      DO 83 IK=1,NRSEGS
      TSSUM=TSSUM+TSUBBS(IK)
 83   CONTINUE
      TSAVG=TSSUM/TOTSEG
      IF (TSAVG .LT. TAVCHK)  GO TO 81
           QU=QROOM1
           QSTFMC=0.0
           IFLAG=0
           GO TO 11
C
C
C     NO DIRECT COLLECTOR HEAT AVAILABLE FOR THE ROOMS' NEEDS SO
C     SEE IF STORAGE CAN SUPPLY THE ENERGY REQUIRED
 121  DLTIME=DLTIMH
      TSSUM=0.0
      DO 91 IK=1,NRSEGS
```

```
      TSSUM=TSSUM+TSUBBS(IK)
 91   CONTINUE
      TSAVG=TSSUM/TOTSEG
      IF (TSAVG .LE. TSURS)  GO TO 40
      IF (IIFLAG .LE. 8)  GO TO 122
      WRITE (5,1019)
      WRITE (5,1021) IHOURB, IHOURE
      WRITE (5,101) (TSUBBS(L3),L3=1,NPSEGS)
 122  QADTOT=0.0
      SUMINT=0.0
      IFLAG=0
      QPBI=0.0
      DSCHGT=60.0
      DO 8 I3=1,NRSEGS
      QPBI=RHOLAN*SPHTPB*(1.0-VOIDR)*TSUBBS(I3)+QPBI
 8    CONTINUE
      IFLAGS=0
      IFLAGG=0
      IFLAGH=0
 123  TSUBFS(NRSEG1)=TSURR
      DO 13 K1=1,NRSEGS
      K=NRSEG1-K1
      TSUBFS(K)=(TSUBFS(K+1)-TSUBBS(K))*EXP(-(HALMCN))+TSUBBS(K)
 13   CONTINUE
      DO 14 L1=1,NRSEGS
      L=NRSEG1-L1
      TSBBSH(L)=((MDOT*SPHTFL*(TSUBFS(L+1)-TSUBFS(L))-USUBLS*0.001*
     1          SURFAR*(TSUBBS(L)-TSURS))*DSCHGT)/(RHOLAN*(1.0-VOIDR)
     2          *SPHTPB)+TSUBBS(L)
 14   CONTINUE
      QPBF=0.0
      DO 9 I4=1,NRSEGS
      QPBF=RHOLAN*SPHTPB*(1.0-VOIDR)*TSBBSH(I4)+QPBF
```

```
 9    CONTINUE
      QADINT=QPBI-QPBF
 605  IF (QADINT .GT. 0.0)  GO TO 830
           QRMFMS=0.0
           GO TO 11
 830  IF (IFLAGG .EQ. 3)  GO TO 836
      IF (IFLAGG .EQ. 2)  GO TO 835
      QRM2M=(QROOM*3.6)/(DLTIME/60.0)
      QRATIO=QADINT/QRM2M
      IF (QRATIO .GT. 0.10)  GO TO 831
           QRMFMS=QADTOT/3.6
           DLTIME=(DLTIME-SUMINT)
           DLTIMA=((QROOM-QADTOT/3.6)/QSUBLS)*DLTIMH
           IF (DLTIMA .GT. DLTIME)  GO TO 11
               DLTIME=DLTIMA
               GO TO 11
 831  QATOT1=QADTOT
 836  IF (IFLAGG .EQ. 3)  QADTOT=QATOT1
 835  QADTOT=QADINT+QADTOT
 839  QCHK=QROOM*3.6-QADTOT
      IF (QCHK .GT. 0.0)  GO TO 841
      IF (IFLAGG .EQ. 2)  GO TO 841
      QCHK1=ABS(QCHK/(QROOM*3.6))
      IF (QCHK1 .LE. 0.01)  IFLAGH=1
      IF (QCHK1 .LE. 0.01)  GO TO 841
           DSCHGT=5.0
           IFLAGG=3
           IF (IFLAGS .EQ. 1)  IFLAGH=1
           IF (IFLAGS .EQ. 1)  GO TO 841
           IFLAGS=1
           GO TO 123
 841  DO 5 I6=1,NRSEGS
      TSUBBS(I6)=TSBBSH(I6)
```

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 5    CONTINUE
      QPBI=QPBF
      SUMINT=SUMINT+DSCHGT
      IF (IFLAGH .EQ.1)  GO TO 843
      IF (IFLAGG .EQ.3)  IFLAGG=2
      IF (SUMINT .LT. 3600.0)  GO TO 832
           QRMFMS=QADTOT/3.6
           DSCHGT=60.0
           DLTIME=0.0
           GO TO 11
 832  IF (QCHK .GT. 0.0)  GO TO 123
 843       DSCHGT=60.0
           QRMFMS=QADTOT/3.6
           DLTIME=0.0
           GO TO 11
C
C     COLLECTOR HAS SUPPLIED ENERGY TO THE ROOM, WAS IT ENOUGH?
 411  IF ((QROOM1-QU) .LT. 0.0)  GO TO 820
           QSTFMC=0.0
           QRMFMC=QU
           QRMFMS=0.0
           GO TO 40
 820  QRMFMS=0.0
           QRMFMC=QROOM1
           TSBFI=TSUBBS(NRSEGS)
           DLTIME=(QROOM1/QU)*DLTIMH
           IFLAG=1
C
C
 40   IF (IIFLAG .LE. 8)  GO TO 11
      WRITE (5,1019)
      WRITE (5,1021) IHOURB, IHOURE
      WRITE(5,101) (TSUBBS(L3),L3=1,NRSEGS)
```

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 11    QPBS=0.0
       DO 15  I3=1,NRSEGS
       QPBS=RHOLAN*SPHTPB*(1.0-VOIDR)*TSUBBS(I3)+QPBS
 15    CONTINUE
       DO 12 L=1,NRSEGS
       TSUBBS(L)=(-(USUBLS*0.001*SURFAR*(TSUBBS(L)-TSURS))*
      1          DLTIME)/(RHOLAN*(1.0-VOIDR)*SPHTPB)+TSUBBS(L)
 12    CONTINUE
       QPBE=0.0
       DO 16  I3=1,NRSEGS
       QPBE=RHOLAN*SPHTPB*(1.0-VOIDR)*TSUBBS(I3)+QPBE
 16    CONTINUE
       QRMFMS=QRMFMS+(QPBS-QPBE)/3.6
       QAUX=QROOM
       IF  (II .GE. 10)  GO TO 50
       IF  (IFLAG .EQ. 1)  GO TO 95
       QAUX=QROOM-QRMFMS-QRMFMC
       IF (QAUX .GE. 0.0)  GO TO 95
            QXCES=ABS(QAUX)
            QAUX=0.0
 95    IF (IFLAG .EQ. 1)  DLTIME=(DLTIMH-DLTIME)
       IF (IFLAG .EQ. 1)  GO TO 111
       GO TO 50
C
C
C
 10    FORMAT(12F5.0)
 101   FORMAT (1H+,(14X,10F10.3))
 1001 FORMAT (1H1,T52,'JANUARY'/)
 1002 FORMAT (1H1,T52,'FEBRUARY'/)
 1003 FORMAT (1H1,T52,'MARCH'/)
 1004 FORMAT (1H1,T52,'APRIL'/)
 1005 FORMAT (1H1,T52,'MAY'/)
```

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 1006 FORMAT (1H1,T52,'JUNE'/)
 1007 FORMAT (1H1,T52,'JULY'/)
 1008 FORMAT (1H1,T52,'AUGUST'/)
 1009 FORMAT (1H1,T52,'SEPTEMBER'/)
 1010 FORMAT (1H1,T52,'OCTOBER'/)
 1011 FORMAT (1H1,T52,'NOVEMBER'/)
 1012 FORMAT (1H1,T52,'DECEMBER'/)
 1014 FORMAT (1H0,T53,'HOURLY',T64,'HOURLY',T76,'HOURLY',T88,'HOURLY',
     1       T100,'HOURLY',T113,'HOURLY')
 1015 FORMAT (1H ,T27,'HOURLY',T40,'HOURLY',T54,'ROOM',T63,'COLLECTED',
     1       T76,'STORAGE',T87,'COLLECTED',T99,'AUXILIARY',
     2       T112,'STORAGE')
 1016 FORMAT (1H ,T15,'AMBIENT',T26,'INCIDENT',T40,'USEFUL',T54,'HEAT',
     1       T64,'HEAT TO',T76,'HEAT TO',T88,'HEAT TO',T100,'HEAT TO',
     2       T114,'LOSS')
 1017 FORMAT (1H ,T16,'TEMP',T28,'HEAT',T41,'HEAT',T53,'NEEDS',T65,
     1       'ROOM',T77,'SURR',T88,'STORAGE',T101,'ROOM',
     2       T113,'TO SURR')
 1018 FORMAT (1H ,T7,'HOUR',T17,'(C)',T27,'(W-HR)',T40,'(W-HR)',T53,
     1       '(W-HR)',T64,'(W-HR)',T76,'(W-HR)',T88,'(W-HR)',T100,
     2       '(W-HR)',T113,'(W-HR)'/)
 1019 FORMAT (1H ,T8,'-')
 1021 FORMAT (1H+,T6,I2,T9,I2)
 1022 FORMAT (1H+,T16,F5.2,T26,F7.1,T40,F7.1,T52,F7.1,T64,F7.1,T76,
     1       F7.1,T88,F7.1,T100,F7.1,T112,F7.1)
 1023 FORMAT (1H0,T6,'MONTHLY')
 1024 FORMAT (1H ,T6,'TOTALS')
 1025 FORMAT (1H+,T24,F10.1,T37,F10.1,T49,F10.1,T61,F10.1,T73,F10.1,
     1       T85,F10.1,T97,F10.1,T109,F10.1///)
 1027 FORMAT (1H0,T7,'HOUR',T25,'STORAGE SEGMENT TEMPERATURE AT BEGINNI
     1NG OF HOUR INDICATED'/)
 20   CONTINUE
      END
PROGRAM  *MAIN* HAS    NO ERRORS
```

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R193 Ramsay
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